STATE OF ALASKA
DEPARTMENT OF NATURAL RESOURCES

INVESTIGATION OF ALASKA'S URANIUM POTENTIAL

By
Gilbert R. Eakins
Robert B. Forbes

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Part 1

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Gilbert R. Eakins

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ABSTRACT

Of the various geographical regions in Alaska that were examined in an exhaustive literary search for the possibility of uranium---either vein type or sedimentary---six offer encouragement: the Copper River Basin, the alkaline intrusive belt of west-central Alaska and Selawik Basin area, the Seward Peninsula, the Susitna Lowland, the coal-bearing basins of the north flank of the Alaska Range, the Precambrian gneisses of the USGS 1:250,000 Goodnews quadrangle, and Southeastern Alaska, which had the sole operating uranium mine in the state.

Other areas that may be favorable for the presence of uranium include the Yukon Flats area, the Cook Inlet Basin, and the Galena Basin.

INTRODUCTION

This report consists of two parts. Part 1, by G.R. Eakins, is the text resulting from a literature search of geologic reports for information pertinent to determining the uranium potential of Alaska, with emphasis on nonmarine sedimentary rocks in structural basins. Part 2 is a 1:1,000,000 scale map of the felsic rocks in Alaska with accompanying analytical data and age determinations compiled by Dr. Robert B. Forbes of the University of Alaska Geophysical Institute. The two parts complement each other in judging the favorability of areas for uranium deposits.

The approach to a study involving an area as vast as Alaska could take many different forms, but for the time allotted it was most expedient to simply divide the state into geographical divisions, and using the criteria now generally used in producing uranium districts, compile from the available materials that information considered to be most helpful in estimating the uranium potential and in serving as a practical guide to exploration.

The first seven figures are for general reference and are not mentioned elsewhere. Figure 1 is a map of Alaska showing the principal features; figure 2 is an index map showing the 1:250,000 scale topographic quadrangle maps published by the U.S. Geological Survey; figure 3 is a generalized correlation chart of the Tertiary rocks in Alaska; and figure 4 shows the Late Mesozoic and Tertiary tectonic features of the state. Figure 5 is a generalized map of the felsic intrusive rocks. Figure 6 shows the principal sedimentary basins, and figure 7 shows both sedimentary basins and felsic intrusive rocks.

HISTORY OF URANIUM INVESTIGATIONS IN ALASKA

Numerous small-scale investigations for radioactive minerals in Alaska were conducted by the U.S. Geological Survey during the late 1940's and early 1950's on behalf of the U.S. Atomic Energy Commission. One of the principal methods used was to concentrate the heavy fraction from stream gravels and test it for radioactivity in hopes of locating concentrations or source areas. Many of the mines and mine dumps were also tested for radioactivity, and spot checks of bedrock outcrops were made in many areas. No commercial deposits were located, but anomalous radioactivity and trace amounts of uranium and thorium were reported from scattered locations. The two regions where anomalous

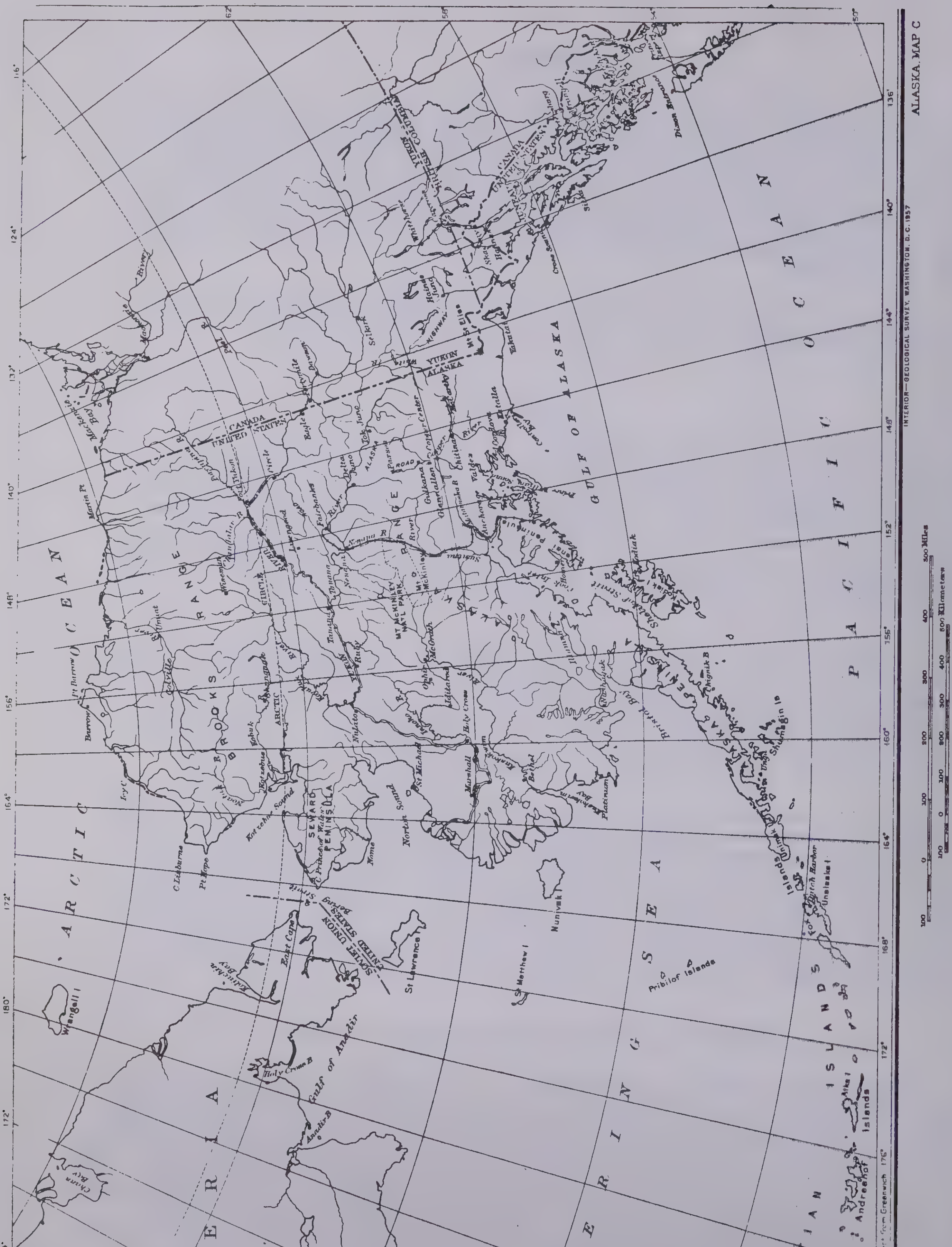


Figure 1. Alaska.

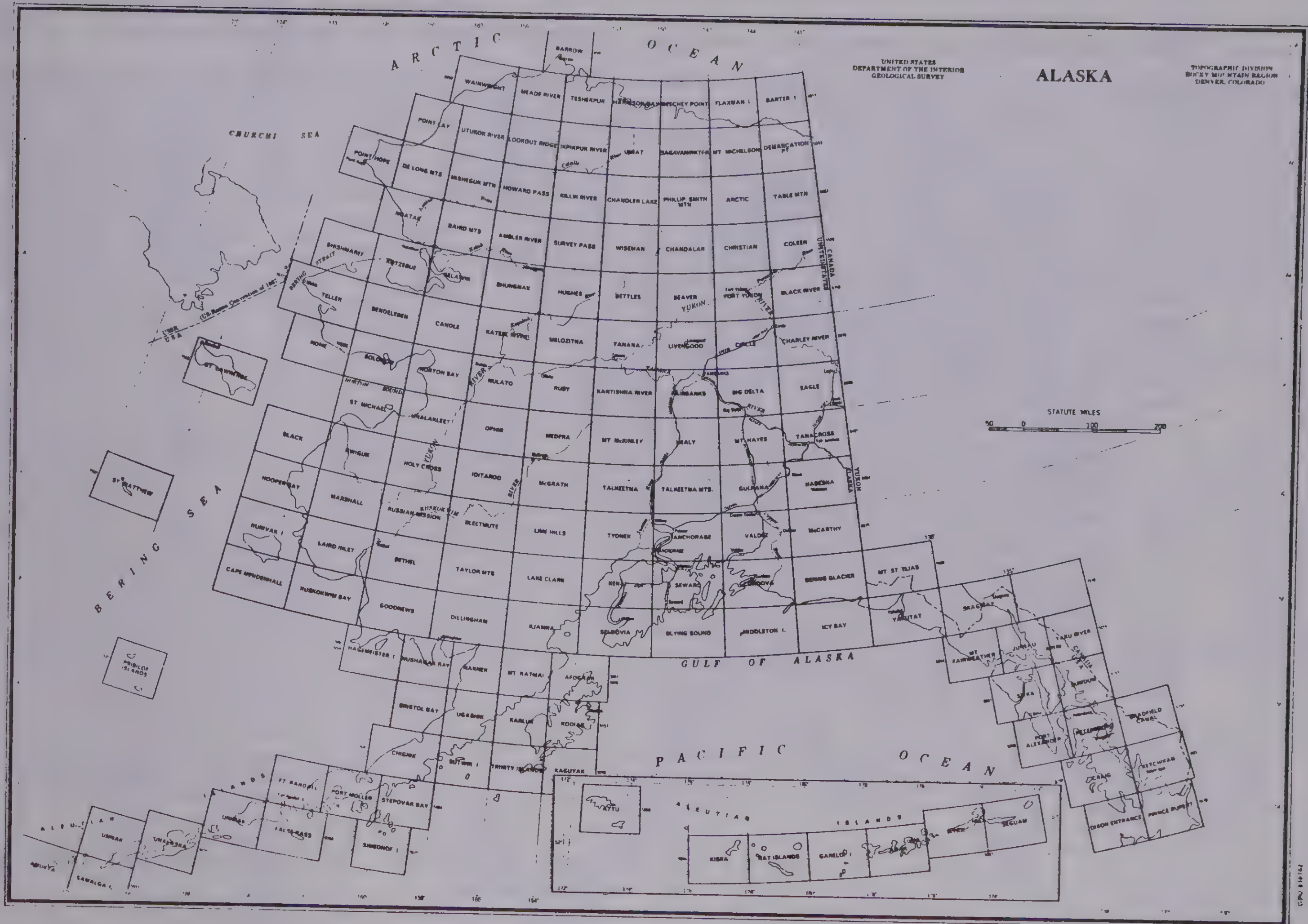


Figure 2. Index to 1:250,000-scale quadrangles in Alaska.

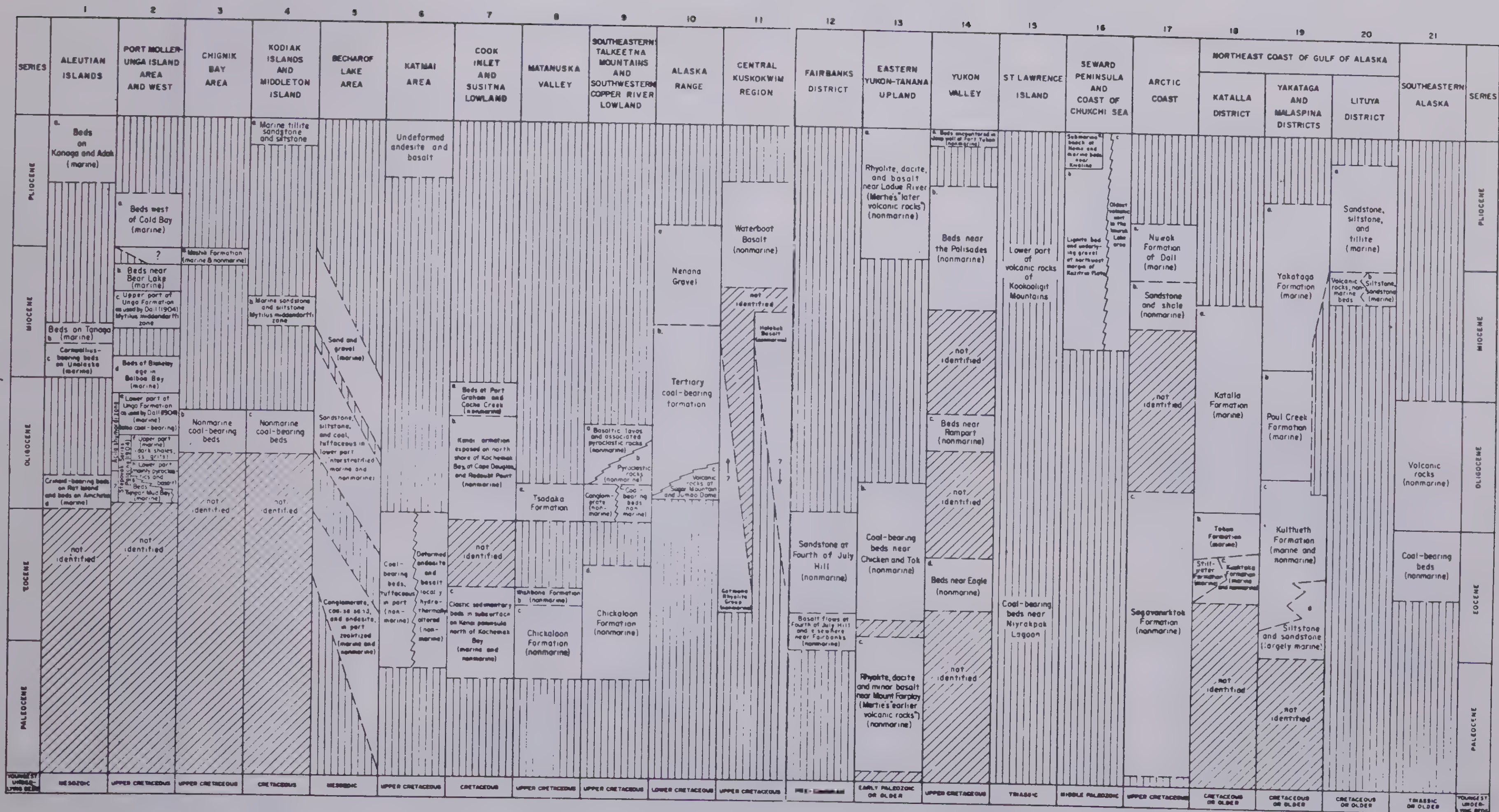


Figure 3. Correlation of Tertiary rocks in Alaska. (Source: Wolf and Miller, 1961, Am. Assoc. Petroleum Geologists Bull., Nov., p. 1802-03.)

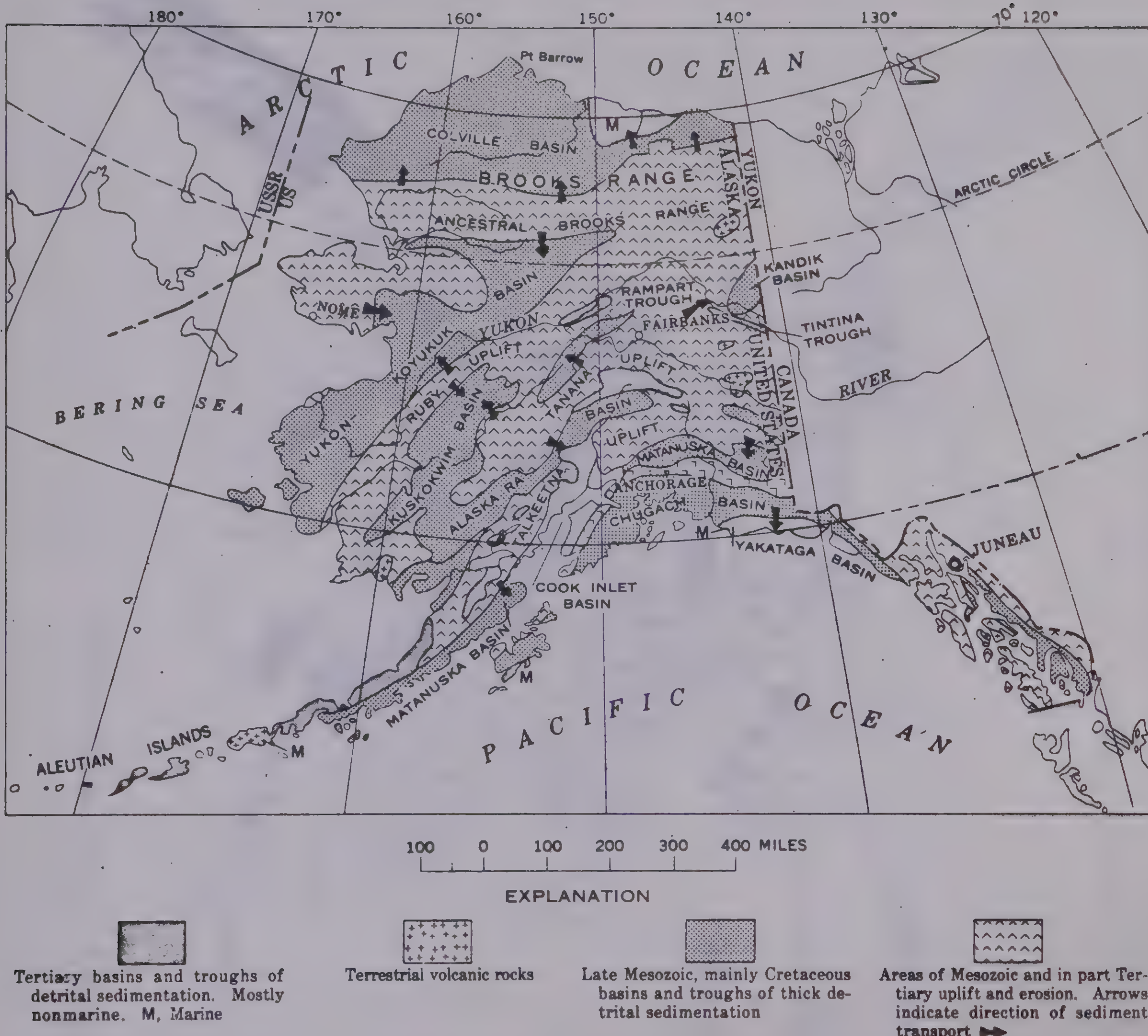


Figure 4. Late Mesozoic and Tertiary tectonic features. (Source: Churkin, 1973, U.S. Geol. Survey Prof. Paper 740, p. 42.)

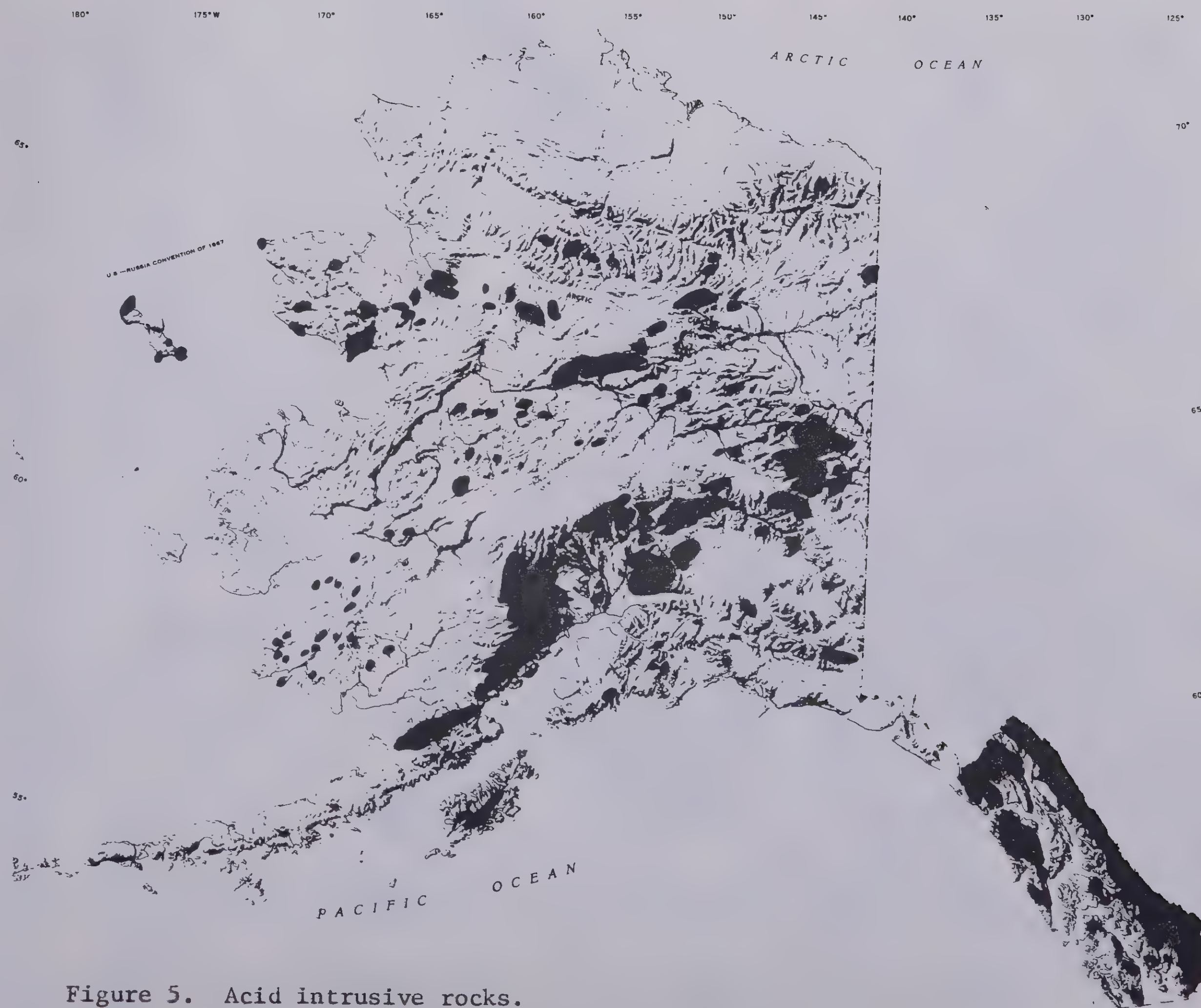


Figure 5. Acid intrusive rocks.

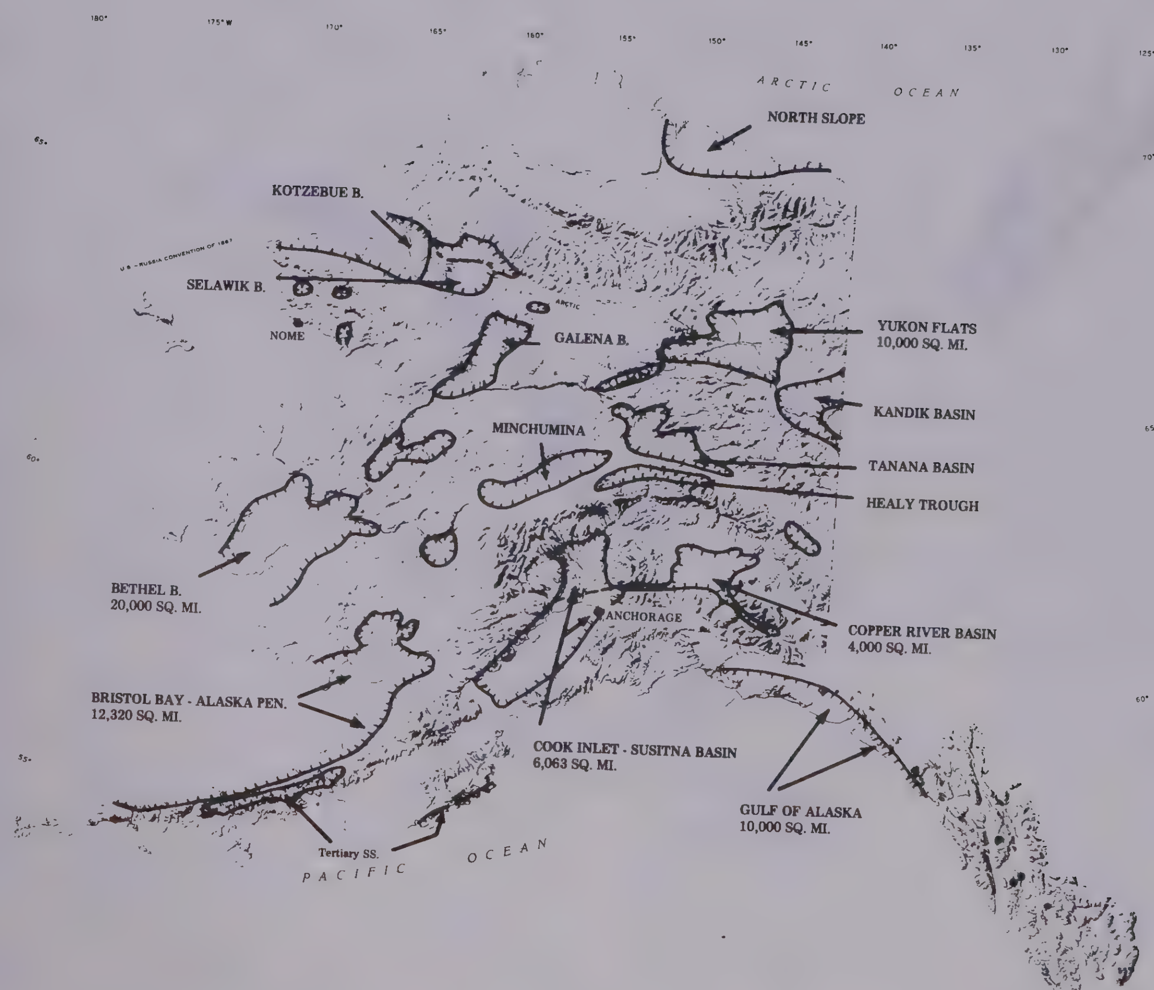


Figure 6. Sedimentary basins in Alaska.

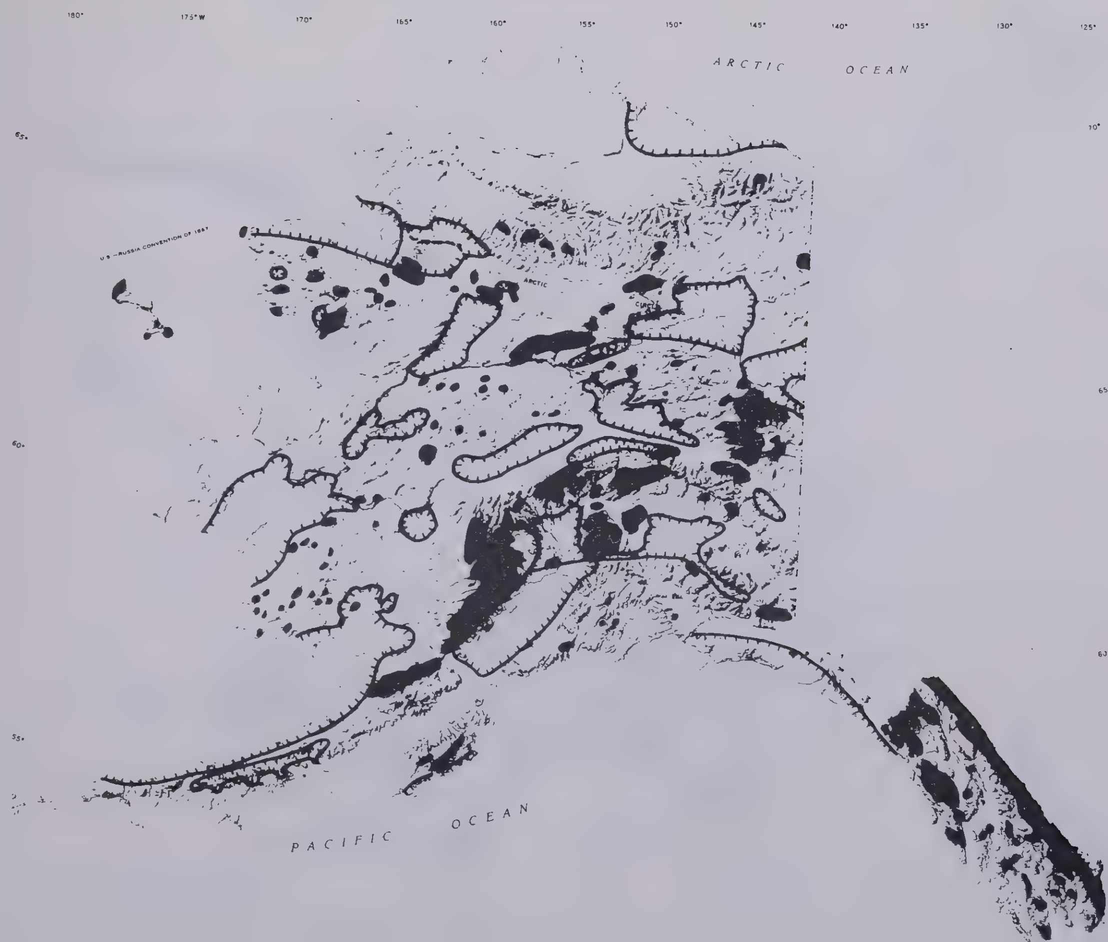


Figure 7. Sedimentary and acidic rocks in Alaska.

radioactivity was most frequently found were the Seward Peninsula and the panhandle of Southeastern Alaska, which are also two of the most highly mineralized parts of the state.

Results of the investigations by the USGS were first published for limited distribution as Trace Elements Investigations Reports (TEIR) or Trace Elements Memorandum Reports (TEMR). Later these were republished as standard USGS circulars. Some of the more recent investigations for radioactivity have been reported in USGS bulletins. A good outline of the Alaskan investigations between 1945 and 1954 was published as TEIR 577 (Wedow, 1956). A tabulation of all the published data on radioactive studies in Alaska was published by the State Division of Geological Survey (Eakins, 1969); and a map showing the location of known occurrences of minerals containing uranium, thorium, or rare-earth elements was published by the USGS (Cobb, 1970).

While there is no way of knowing how much of the state has been explored for uranium by private companies and individuals, reports on activities in the state indicate that exploration has not been very extensive. The only commercial uranium deposit found to date in Alaska was discovered in 1955 by two amateur Ketchikan prospectors, Don Ross and Kelly Adams, using an airborne geiger counter; they found radioactivity at Bokan Mountain, near Kendrick Bay on Prince of Wales Island. The deposit seems to be unique: the host rock is a small stock of peralkaline granite; and the nature of the deposit itself may best be described as grain coatings and fracture fillings in a microbreccia zone in the granite. The deposit, though small by most standards, was high grade, easily accessible, and close to water transportation.

It is perhaps more important to point out what has not been done to investigate the uranium possibilities in Alaska than to elaborate on what has been done. Very little aerial radiometric surveying has been conducted with suitable equipment, and few systematic geochemical programs have been employed. Practically no drilling or excavating has been done to test the subsurface, so that little information is available on the sedimentary basins. A loss of data has resulted from failure of petroleum companies to run complete radioactivity logs on most exploration and development wells. The reasons for such a vast region as Alaska remaining relatively unexplored for uranium are (1) a lack of geological information, (2) the remoteness of most areas and accompanying high cost of operations, and (3) the lack of demand for additional uranium during the past several years. There are other problems peculiar to exploring for uranium in Alaska as well: large regions are covered by swamp or muskeg, permafrost is present over a large part of the state, the climate is radically different from the Colorado Plateau and Wyoming basin where sedimentary type deposits are located, and the structural complexity and degree of metamorphism of Alaskan rocks are more pronounced than in most known uranium districts.

This picture can be expected to change, and perhaps rather quickly. The present energy crisis has resulted in several exploration companies undertaking uranium programs in the state in 1974. Others are collecting information and are considering the possibility of initiating uranium investigations. The methods reportedly favored are geochemical prospecting by stream-sediment and water sampling, and aerial radiometric surveying. Many new data are certain to be generated as a result of these efforts.

GULF OF ALASKA TERTIARY PROVINCE

Bedded volcanic and sedimentary rocks of Tertiary age occur in a 625-mile-long arc along the margin of the Gulf of Alaska. They extend intermittently from the Kodiak Island group on the west to Icy Point in southeastern Alaska. Total thickness of the sequence is believed to exceed 25,000 feet in the eastern part of the belt (Miller, Payne, and Gryc, 1959, p. 40), and even greater thicknesses may lie offshore. The ages of the sediments and intrusive rocks are believed to range from Eocene through lower Pleistocene, but because of the structural complexities and a paucity of diagnostic fossils and marker beds, the age relationships of the various formations are not well known. Rapid deposition is indicated by the thick accumulation and relatively poor sorting. While most of the sediments are of marine origin, a considerable portion of the Eocene is nonmarine in the eastern portion of the Gulf of Alaska. Large areas along the coast are masked by Quaternary deposits and glaciers and ice fields. Small intrusive stocks are present in many areas; these are Mesozoic or Tertiary and vary in composition from ultramafic to granitic.

The belt of Mesozoic rocks bordering the Gulf of Alaska from Kodiak Island to southeastern Alaska underlies the Tertiary sediments and crops out further inland. Mesozoic rocks are largely marine slates, graywackes, and greenstones. These are regarded as generally unfavorable for sedimentary uranium deposits because of their metamorphism and complex structures. Any favorable characteristics noted in the descriptions of Mesozoic rocks in the Gulf of Alaska will, however, be indicated in this section.

For convenience in describing the geology and examining the uranium potential, the Gulf of Alaska Tertiary province is divided into four districts: the Eastern district; Prince William Sound; the Kenai Peninsula; and the Kodiak Island group.

EASTERN PART OF THE GULF OF ALASKA

The eastern district of the Gulf of Alaska Tertiary Province extends about 300 miles along the border of the Gulf from the mouth of the Copper River southeastward to Icy Point (fig. 8). It is a subdivision of the Pacific Mountain System. Tertiary rocks lie in a belt up to 40 miles wide between the coast and the Chugach and St. Elias Mountains. The St. Elias range is the most prominent feature in this province, with peaks to 18,008 feet high. The foothills on the coastal side of the range rise abruptly 3,000 to 4,000 feet, and the coastal plain between the Gulf of Alaska and the foothills varies from 1/2 to 15 miles wide. Exposures are not continuous along the belt, but Tertiary rocks are believed to extend beneath ice and alluvium near the coast and they almost certainly form a continuous belt beneath the offshore waters. Outcrops of Tertiary rocks are most abundant in the Katalla area, which includes the Bering River coal field, and in the Yakataga area between the Bering and Guyot Glaciers. Tertiary sediments are not exposed between Malaspina Glacier and Lituya Bay, but from Lituya Bay southeast to Icy Point they are present again for a distance of about 25 miles.

The best map reference is the geologic map of the Gulf of Alaska Tertiary Province, by George Plafker, 1967.

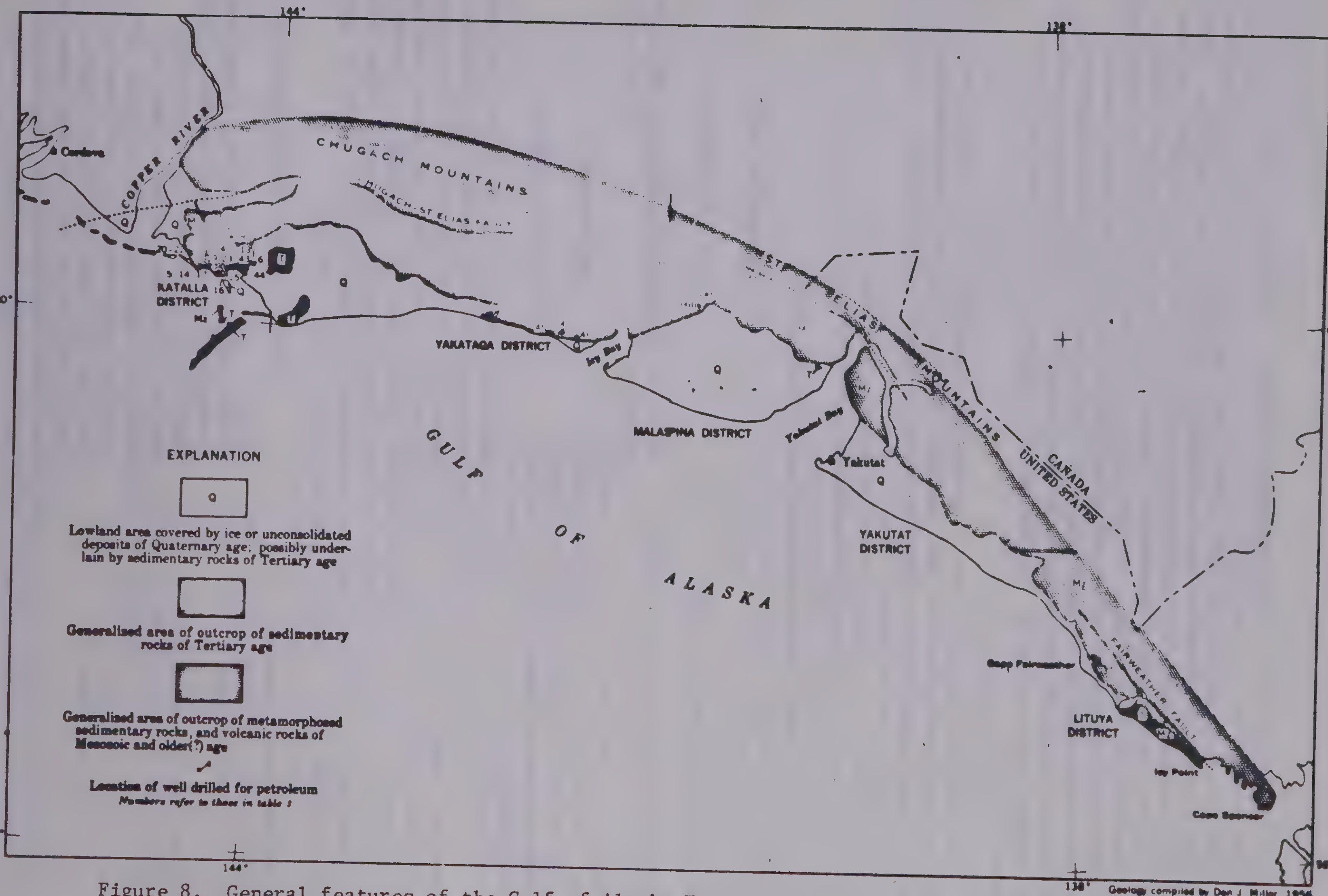


Figure 8. General features of the Gulf of Alaska Tertiary province, southern Alaska. (Source: Miller, 1959, U.S. Geol. Survey Bull, 1094, pl. 5.)

Sedimentary Rocks

The Tertiary section has been subdivided into three general units on the basis of fossils and depositional environments (Miller, Payne, and Gryc, 1959, p. 41). The earliest unit, Eocene to Oligocene, includes interbedded shallow-water marine and nonmarine sediments, characterized by thick beds of arkosic sandstones and numerous beds of high rank coal. The middle unit was deposited in moderately deep water during middle Oligocene to middle Miocene time and includes calcareous siltstone, mudstone, and volcanic tuffs and agglomerate. The youngest unit was deposited from late Miocene to late Pliocene or earliest Pleistocene and consists of shallow marine sandstone or siltstone and interbedded tillite.

The Tertiary sediments rest with angular unconformity on Mesozoic or older folded slates, schists, and gneisses and massive granitic intrusives. The following descriptions summarize the stratigraphy of the region.

Rocks of the Eastern Part of the Gulf of Alaska Tertiary Province

(Descriptions from Plafker, 1967)

	SEDIMENTARY ROCKS
Recent	**Surficial deposits** Alluvial, glacial, lacustrine, and beach deposits.
	UNCONFORMITY
Middle Miocene to lower Pleistocene	**Yakataga Formation** Mudstone, siltstone, sandstone, and minor conglomerate interbedded with abundant conglomeratic sandy mudstone (tillite) characterized by unsorted, striated, and faceted clasts of diverse lithologies. Composite thickness about 16,500 feet. Major intraformational unconformity occurs in upper part of unit. Marine.
Lower and Middle Miocene	**Upper part of Katalla Formation** Pebbly siltstone, siltstone, pebble conglomerate, and sandstone at least 9,200 feet thick. Sparsely fossiliferous. Marine. Includes youngest rocks of uncertain age that comprise upper part of Katalla Formation in south-central Katalla district. May be in part equivalent in age to Yakataga Formation, but lacks characteristic conglomeratic sandy mudstone (tillite).

Middle and upper Oligocene and lower Miocene	Poul Creek Formation and middle and lower part of Katalla Formation Calcareous siltstone with minor sandstone, glauconite, and pyroclastic volcanic rocks. Thickness from 3,200 to 6,100 feet. Marine. Includes middle and lower parts of the Katalla Formation in the Katalla district and Poul Creek Formation of the Yakataga and Malaspina districts.
	UNCONFORMITY(?)
Upper Eocene and lower Oligiocene	Tokun Formation Interbedded sandstone and concretionary siltstone in upper part; mainly concretionary siltstone in lower part. Between 1,100 and 3,500 feet thick. Marine. Mostly complexly deformed. As mapped, may include basal part of Katalla Formation in northeastern part of Katalla district.
	LOCAL DISCONFORMITY(?)
Middle(?) and upper Eocene and Oligocene(?)	Kushtaka and Kulthieth Formations Arkose, siltstone, and coal. At least 9,000 feet thick. Continental and marine. Mostly complexly deformed with at least one major intraformational unconformity. Includes the Kushtaka Formation of the Katalla district and the Kulthieth Formation of the Yakataga and Malaspina districts. The units in part conformably overlie, and in part intertongue with marine sediments of the Stillwater Formation in the Katalla district, and unnamed related rocks in the Yakataga and Malaspina districts. Age based on marine fauna and continental flora.
Eocene	Stillwater Formation and related unnamed rocks Siltstone, calcareous siltstone, and sandstone of unknown thickness. Marine. Complexly deformed.
Jurassic(?) and Cretaceous	Yakutat Group Graywacke, argillite, and slate with minor conglomerate of unknown thickness. Marine.

Complexly deformed and mildly to moderately metamorphosed. Includes probably synchronous Sitka Graywacke (Upper Jurassic and Lower Cretaceous) on Yakobi Island and, elsewhere, may locally include rocks of units Mzv, TKi, and To (possibly equivalent to the Valdez group in the Prince William Sound area).

Mesozoic and older(?)	Crystalline complex Includes granitic rocks, schist, gneiss, amphibolite, and marble; complexly deformed and moderately to intensely metamorphosed. In part may be derived from (or include rocks of) units Mzv, KJy, and TKi.
Tertiary units present in the Lituya Bay---Icy Point area only - Oligocene(?) to pre-middle Miocene	Topsy Formation and Cenotaph Volcanics (new names) Includes lower portion of hitherto unnamed volcanic and sedimentary sequence in Lituya district (formations "A" and "B" of Miller, 1961b). The name Cenotaph Volcanics is herein applied to an unfossiliferous unit about 1,250 feet thick characterized by green, red, and purple andesitic volcanic breccia, tuff, and flows interbedded with tuffaceous siltstone, glauconitic sandstone, pebble-cobble conglomerate and minor coal. Type section is designated along south shore of Cenotaph Island in Lituya Bay. Probably continental and marine. The Cenotaph Volcanics intertongues with, and is in part unconformably overlain by, a sparsely fossiliferous marine unit consisting of about 1,200 feet of hard calcareous siltstone and sandstone, herein named the Topsy Formation
Tertiary unit present west of Katalla oil field only. In part middle and late Eocene age	Orca Group and related unnamed rocks Argillite, calcareous argillite, sandstone, and altered mafic pillow flows, breccias, and shallow intrusives; sparsely fossiliferous; marine. Complexly deformed. Includes the early Tertiary Orca Group in the Prince William Sound region (Plafker and MacNeil, 1966).

The Eocene Kushtaka and Kulthieth Formations are probably the most interesting with respect to uranium exploration. These formations are probably equivalent in age and are largely nonmarine in origin. Figures 9 and 10 provide a more detailed description of the arkosic sandstones, coal beds, and general characteristics of this unit.

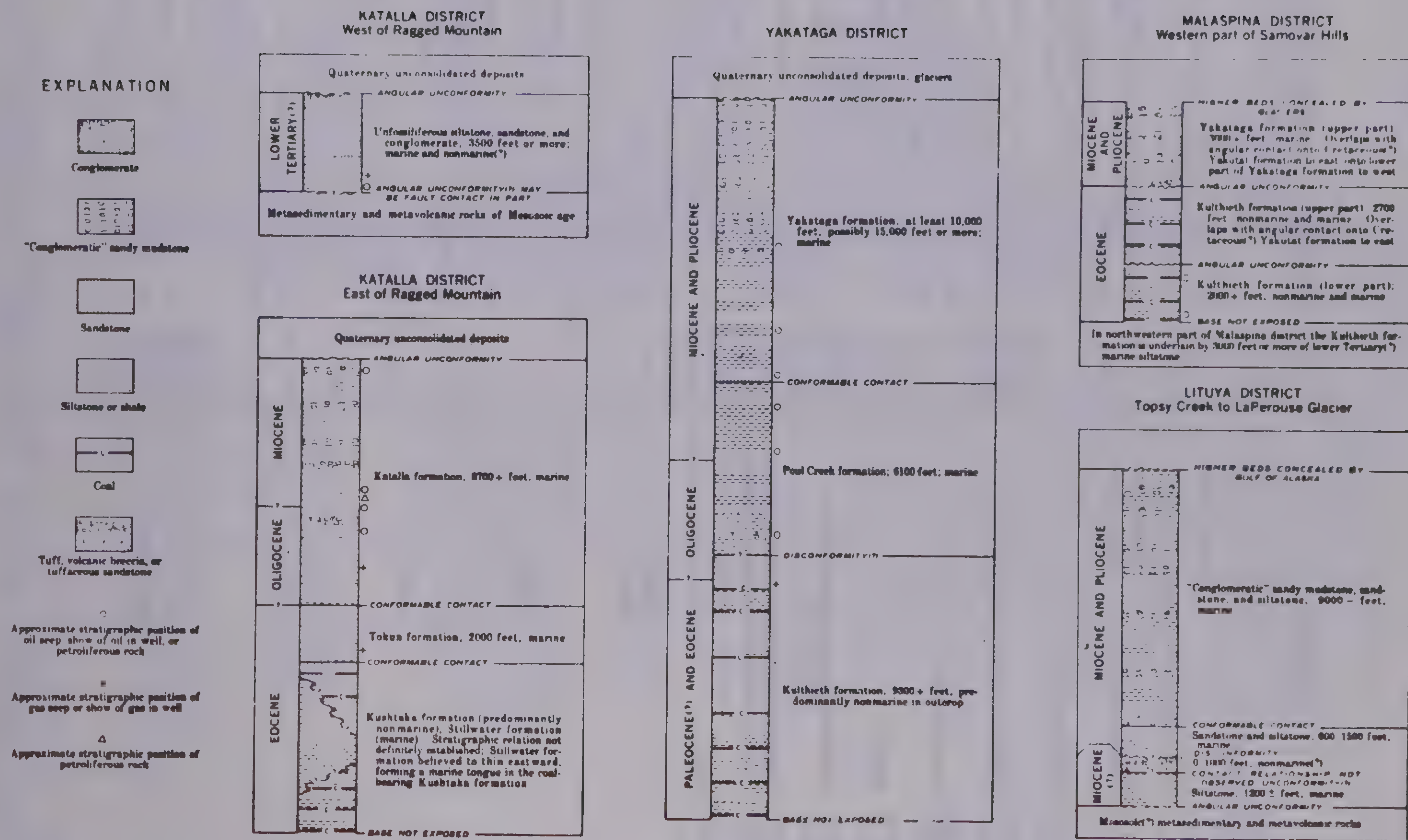


Figure 9. Representative stratigraphic sections of the Tertiary sequence exposed in the Gulf of Alaska Tertiary province, southern Alaska. (Source: Miller, 1959, U.S. Geol. Survey Bull. 1094, pl. 6.)

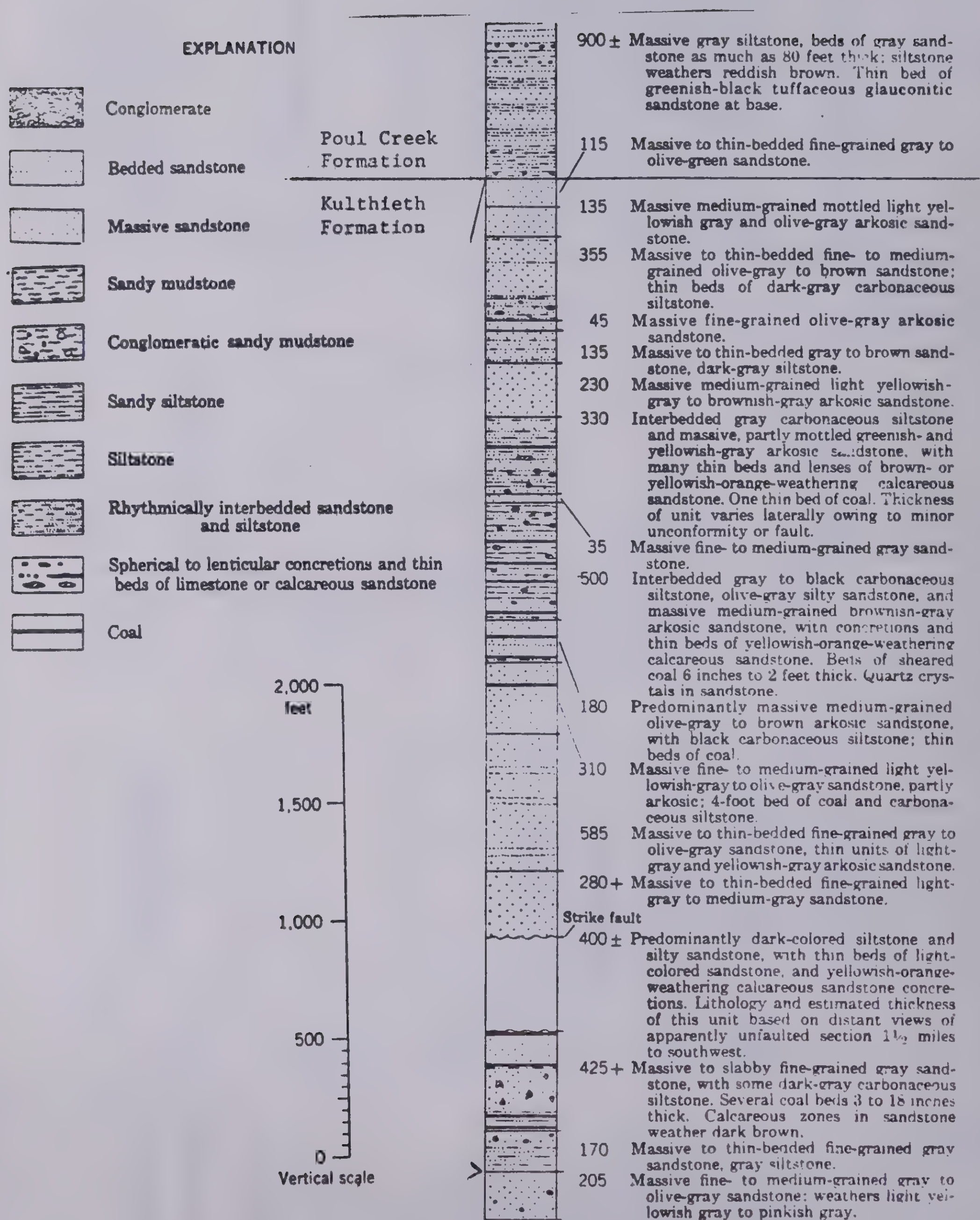
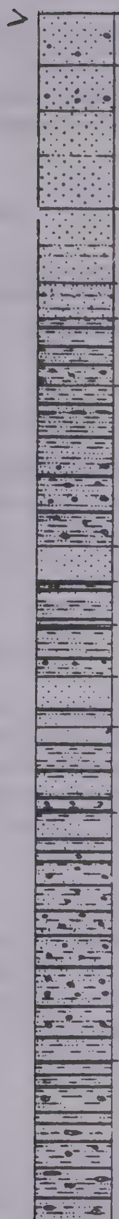


Figure 10. Portion of the Kulthieth River section showing lithology of the Kulthieth Formation. (Source: Miller, 1957, U.S. Geol. Survey Oil and Gas Inv. Map OM-187.)



205 Massive fine- to medium-grained gray to olive-gray sandstone; weathers light yellowish gray to pinkish gray.

580 ± Predominantly massive fine-grained sandstone, in part yellowish, olive or brownish gray, arkosic, mottled; in part light to dark gray; in part olive gray, weathering pinkish gray. Thin beds of dark-gray siltstone. Total thickness of this unit uncertain owing to possible error in correlating beds across covered interval and a minor fault.

295 Massive very fine grained olive-gray-weathering gray sandstone, thin beds of carbonaceous siltstone.

145 Massive to thin-bedded fine-grained gray sandstone, thin beds of gray siltstone.

275 Olive-gray to black carbonaceous siltstone and silty sandstone with many concretions and thin beds of yellowish-orange-weathering calcareous sandstone; six beds of coal 3 inches to 5 feet thick.

650 Gray to black carbonaceous siltstone and silty sandstone with thin beds of friable gray to brown arkosic sandstone. many concretions and thin beds of yellowish-orange-weathering calcareous sandstone, and beds of coal 6 inches to 4 feet thick. Quartz crystals in sandstone.

135 Massive friable medium-grained gray to brown arkosic, partly calcareous sandstone; quartz crystals.

180 Grayish-brown sandstone and gray siltstone; four beds of coal 6 inches to 6 feet thick.

210 Dark-gray siltstone and brown sandstone with yellowish-orange-weathering calcareous sandstone concretions; three beds of coal 2 to 5 feet thick.

200 Massive medium-grained light yellowish gray arkosic sandstone; thin beds of carbonaceous siltstone and coal.

340 Massive to thin-bedded fine-grained sandstone, black carbonaceous siltstone, several beds of coal 3 to 18 inches thick.

1,000 Predominantly dark-gray to black carbonaceous siltstone and silty fine-grained sandstone interbedded with friable medium-grained light-gray to brown arkosic sandstone; some thick units of crossbedded rhythmically interbedded sandstone and siltstone, many concretions and thin beds of yellowish-orange-weathering calcareous sandstone, and many thin beds of coal.

650+ Predominantly dark-gray to black carbonaceous siltstone, with thin units of gray to brown arkosic sandstone, many concretions and thin beds of yellowish-orange-weathering calcareous sandstone, and many thin beds of coal.

Base of measured section on tributary of Duktoth River about half a mile southeast of low pass between Duktoth River and eastern arm of Bering Glacier. Beds of the Kulthieth formation exposed farther downstream on the tributary are complexly folded and faulted, and may be largely or entirely represented in the lower part of the section described above

Figure 10. Portion of Kulthieth River section showing lithology of the Kulthieth Formation (cont.).

Igneous Rocks

Age	Unit
Upper Oligocene and lower Miocene	**Porphyritic intrusive igneous rocks** Predominantly porphyritic felsic plugs of post-middle Katalla age in the Katalla district.
Upper Eocene and lower Oligocene	**Granitic rocks** Chiefly porphyritic granite and quartz monzonite of probable late Eocene and early Oligocene age in the Prince William Sound region.
Cretaceous or Tertiary	**Intrusive igneous rocks** Mainly quartz diorite and granodiorite with minor quartz monzonite and mafic intrusive rocks. Age uncertain, but probably largely Cretaceous or earliest Tertiary.
Mesozoic and older(?)	**Volcanic rocks** Predominantly greenstone and volcanic graywacke with minor argillite, chert, and limestone of unknown thickness. Complexly deformed and mildly to moderately metamorphosed. Locally may include rocks of unit To.

The Tertiary Cenotaph volcanic rocks underlie about 20 square miles in the Lituya Bay area. The unit is approximately 1,250 feet thick and includes volcanic breccia and tuff, sandstone, conglomerate, siltstone, and coal (Plafker, 1967). The presence of tuffs and light-colored granite in the nearby Deception Hills suggest possible source materials for uranium, and the coal could be a reductant.

Structure

The Tertiary rocks in this region have been complexly folded and faulted by at least three stages of deformation: Mid-Jurassic--Early Cretaceous; Late Cretaceous or Early Tertiary; and between Tertiary and Quaternary (Pliocene or Pleistocene). A series of high-angle thrust faults strike approximately parallel to the coast. The degree of deformation increases northward along the mountain fronts. Dips of the sedimentary rocks are usually greater than 20 degrees and as much as 80 degrees. The cross section in figure 11 is an example of the structural conditions in this region; this section is less complex than most of the area.

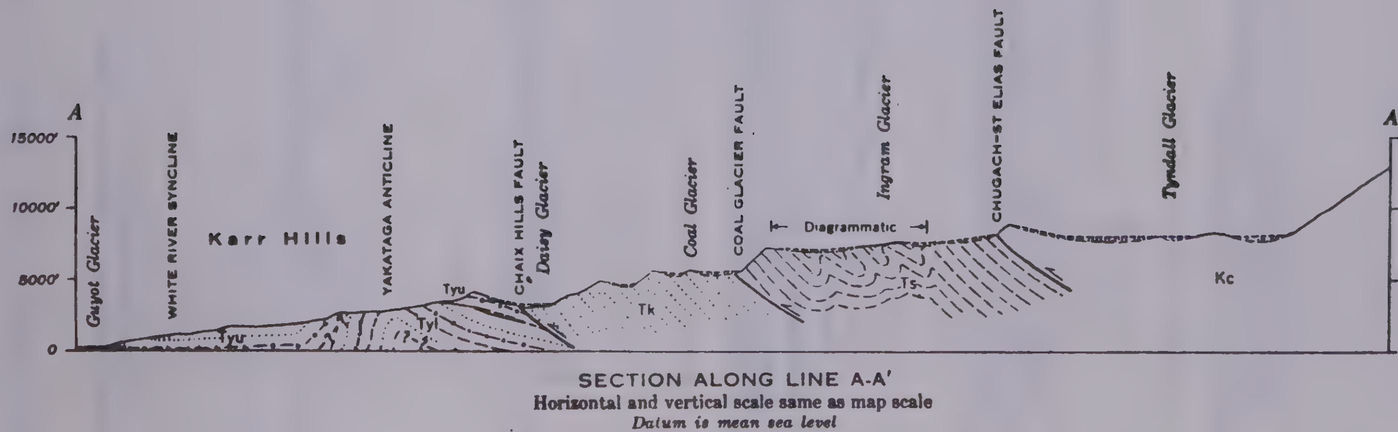


Figure 11. Example of the structure in the Gulf of Alaska Tertiary province. Section trends NNE from near the head of Icy Bay. (Source: Plafker and Miller, 1957, U.S. Geol. Survey Oil and Gas Inv. Map OM-189.)

EXPLANATION

Qd

Unconsolidated deposits

Includes fluvial and marine gravel, sand, and mud; nonmarine and marine glacial till; and landslide debris.

Pleistocene(?) and Recent — QUATERNARY

UNCONFORMITY

Tyu

Tyl

LOCAL UNCONFORMITY

Yakataga formation

Siltstone and sandstone interbedded with massive conglomeratic sandy mudstone (tillite), marine, Tyu; *dominantly uniformly bedded siltstone and sandstone, marine,* Tyl.

Miocene and Pliocene(?)

UNCONFORMITY

Tk

Tku

Tkl

LOCAL UNCONFORMITY

Kulthieth formation

Sandstone, siltstone, and coal, continental and marine, Tk; *dominantly massive arkosic sandstone and thin-bedded siltstone with minor coal,* Tku; *interbedded arkosic sandstone and siltstone with minor coal,* Tkl.

Paleocene(?) and Eocene — TERTIARY

CONTACT NOT EXPOSED

Ts

Siltstone sequence

Dominantly siltstone with sandstone and minor conglomerate; probably marine.

TERTIARY (?)

UNCONFORMITY

Ky

Yakutat group

Graywacke, argillite, and slate with minor conglomerate; marine.

Upper (?) Cretaceous — CRETACEOUS

UNCONFORMITY

Kc

Crystalline complex

Undifferentiated metamorphic and intrusive rocks.

CRETACEOUS AND OLDER

Figure 11. Example of the structure in the Gulf of Alaska Tertiary province (cont.).

The boundary of the Tertiary province is created by the Chugach-St. Elias fault on the north and the Fairweather fault to the southeast. The Chugach-St. Elias fault is a major structural feature that has been traced for at least 180 miles. It dips 30-60 degrees north and has a stratigraphic throw of at least 10,000 feet.

It is probable that the Tertiary sediments extended farther northward before uplift and erosion occurred.

Economic Geology

Gold

Small-scale placer gold mining has been conducted at intervals along the beaches between Yakataga southeastward to Lituya Bay (Cobb, 1969, p. 5, 13). Both stream and beach placers have been worked sporadically since about 1897, but none ever became important producers. Stream gold is confined to the White River valley near Yakataga.

The immediate source of the beach placers is the fluvioglacial gravels of the coastal plain. Wave action cutting into the shore released the gold particles and concentrated them to some degree on the beach. The principal heavy minerals found in the concentrates are magnetite, garnet, and ilmenite with small to trace amounts of rutile, zircon, chromite, and gold (Thomas and Berryhill, 1962, p. 2). A few small nuggets of copper have been reported (Maddren, 1913, p. 137).

Churn-drill hole sampling was conducted by a private company during 1957 to test the black sands for magnetite content near Yakutat and Lituya Bays (Thomas and Berryhill, 1962, p. 7).

The original source of the heavy metals has not been determined, but the black sands presumably were derived from basic igneous rocks in the region.

Copper

A gabbro dike in granite on the southeast arm of Lituya Bay contains irregular veinlets and blebs of pyrrhotite and chalcopyrite. Also, near Lituya Bay and north of Crilla Glacier a layer in a mafic pluton contains 60 percent ilmenite, and 2-3 percent pyrrhotite and chalcopyrite. Specimens from a contact zone contained 5-6 percent pyrrhotite and chalcopyrite (Berg and Cobb, 1967, p. 195). A claim was staked on a chalcopyrite showing near Yakutat in 1906, but no reports since 1907 have mentioned the occurrence. Noncommercial native copper, malachite and azurite, have been found in volcanic rocks next to the Bagley Icefield, about 30 miles north of Yakataga (Berg and Cobb, 1967, p. 73).

Coal

Coal of Tertiary age is present in the coastal belt at intervals between Cordova and Yakutat Bay to the east. The most important deposits are in the Bering River field 50 miles east of Cordova, north of Controller Bay.

The field is roughly 21 miles long and 2 to 5 miles wide. The coal beds are probably all contained within the Eocene arkosic sequence---the Kushtaka and Kulthieth Formations. The rank of the coal ranges from subbituminous to anthracite; some is of coking quality. The coal occurs in a large number of lenticular and intertonguing beds that vary in thickness from a few inches to 60 feet (Barnes, 1967, p. B30).

A great deal of prospecting has been done on the coal, but because of the structural complexities and transportation problems, no commercial production has been achieved.

Petroleum

Numerous oil and gas seeps near the coast have been known in the Katalla and Yakataga areas since about 1896. Between 1903 and 1933, 154,000 barrels of oil were produced from the Katalla oil field on Controller Bay. The wells produced from the Katalla Formation at depths between 360 to 2350 feet. Interest in possible deeper reservoirs led to 26 drilling tests from 1954 to 1963 between Katalla and Dry Bay, 200 miles southeastward. These wells reached depths between 5,326 and 14,699 feet. Three or four bottomed in the Jurassic(?) and Cretaceous Yakutat group. Oil and gas shows were reported but none was a producer. The sediments penetrated by these Gulf of Alaska wells reported in the well records include principally shale, carbonaceous shale, sandstone, conglomerate, siltstone, volcanic material, and coal.

Interest in the Tertiary and Mesozoic possibilities offshore has become more intense each year, and it is generally believed that the Gulf of Alaska has an excellent chance of becoming a major petroleum province.

Radioactivity Investigations

Four reports have been published that discuss the results of cursory investigations for radioactivity in the eastern Gulf of Alaska district.

Nine samples from beach placers were submitted to the USGS by a prospector and a mining company prior to 1948 (Moxham and Nelson, 1952, p. 11-14). The results of the Survey's analyses of these, done on the behalf of the AEC Division of Raw Materials, are reproduced on the following page.

Comments on the Yakataga samples are quoted from Moxham and Nelson (1952, p. 11, 13):

> *Three radioactive minerals were isolated from the Yakataga samples. One of the samples has been identified definitely as zircon, but optical and X-ray studies of the other two were inconclusive except to show that they belong to the zircon group. Zircon constitutes 95 percent of the nonmagnetic fractions (fraction F) of the three samples listed in (the lower) table. Radiometric tests indicate that the mineral contains 0.2 percent equivalent uranium. Sodium fluoride fluorescence tests for*

uranium were negative, although the high zirconium content may have had a quenching effect. It is likely, however, that the radioactive element is thorium.

Two unidentified radioactive minerals are found in the weakly magnetic fraction (fraction E, lower table). One is black and opaque with a metallic luster. It is highly radioactive and bead tests for uranium were strongly positive. The other unidentified mineral is reddish brown, translucent, has a vitreous luster, and is only moderately radioactive. Bead tests for uranium were negative, so the radioactivity is ascribed to thorium.

Data on beach placer samples from the Yakataga area, southern Alaska

Sample no.	Type of material	Heavy fraction (percent eU)[a]	Heavy fraction (percent U)	Concentration ratio (total sample: heavy fraction)[b]
1355[c]	Natural beach concentrate	0.021	0.016	1.2:1
1356	Amalgamation residue----	.320	.012	1.1:1
1357	Common beach sand------	.000	---	6.7:1
3259[d]	---------- do ----------	.026	.014	1.2:1
3260	---------- do ----------	.018	.006	1.8:1
3261	---------- do ----------	.000	---	9.3:1
3262	---------- do ----------	.003	---	3.8:1
3263	---------- do ----------	.004	---	26.0:1
3264	---------- do ----------	.002	---	4.7:1
Average		.044		

[a]Equivalent uranium.
[b]All samples except 1357 were concentrated to an unknown extent prior to their receipt by the Geological Survey. The concentration ratio given above refers to the heavy minerals in the sample as it was received.
[c]Samples 1355-1357 given by Joe Meloy.
[d]Samples 3259-3264 given by Seymour Standish and Associates.

Equivalent-uranium (eU) content of concentrates from beach placers in the Yakataga area, southern Alaska, by grain size and magnetic fractions

Sample	+20-mesh	-20-mesh						
		Fractions of decreasing magnetic susceptibility						
		A (Strongly magnetic)	B	C	D	E		F (Nonmagnetic)
						+70-mesh	-70-mesh	
1355								
Percent eU	0.000	0.000	0.000	0.000	0.015	0.039	1.727	0.074
Percent of total heavy fraction	4.4	1.4	4.8	67.7	5.8	1.4	2.3	12.1
1356								
Percent eU	.000	.000	.000	.000	.018	.016	3.710	.098
Percent of total heavy fraction	2.5	14.8	7.1	25.3	8.1	3.3	1.8	17.1
3259								
Percent eU	.000	.000	.004	.001	.085	.010	4.475	.514
Percent of total heavy fraction	5.2	22.2	10.3	39.4	9.9	2.9	1.3	8.8

The conclusions were that the radioactive materials and gold were derived from an unknown source in the St. Elias Range. Although one sample contained a uranium-bearing mineral and two contained thorium minerals, the sands do not constitute a feasible source of radioactive materials. A report by Wedow (1956, p. 25, 68) states:

> *Concentrates supposedly from this (Yakataga) area were submitted to the USGS in 1952 and contain as much as 35 percent eU and 19 percent U; the chief radioactive mineral is uranothorianite.*

It was theorized that since the uranothorianite is friable and soluble, it has not been transported any great distance and had a nearby bedrock source. The mineral could have originated in a vein deposit.

A report on this occurrence was in preparation at that time (1956), but this writer has not been able to locate it, and the validity of the assays is questionable.

Thomas and Berryhill (1962) reported on the study of beach sands along 247 miles of coastline to determine if the sand contained economic minerals. A total of 201 3-inch auger holes spaced at approximately 1-mile intervals were bored to depths ranging from 3 to 27 feet. All the samples were tested for radioactivity. Only trace amounts of eU were reported from the concentrates. One assay (Thomas and Berryhill, 1962, table 2), produced 0.007 pounds eU per cubic yard from the nonmagnetic fraction.

The same report (p. 7) states "during the summers of 1955 and 1956, considerable attention was directed toward the radioactive mineral potential of the beach deposits near Yakataga. Several prospectors as well as two private concerns conducted bore-hole sampling programs along the deposits fronting the tidal zone."

The U.S. Geological Survey (Brabb and Miller, 1962) carried a scintillation counter on a north-south reconnaissance traverse across the eastern Chugach Mountains. The traverse extended between a point about 20 miles north of Yakataga, north 52 miles to the Chitina River. The report states, "the results indicate an absence of large fields of radioactivity or significant concentration of radioactive minerals." And, "copper minerals, graphite, pyrite, and hematite were found at several locations, but not in quantities suggesting deposits of commercial value."

Discussion

Detailed investigations for uranium in the Tertiary of the eastern district of the Gulf of Alaska are not known to the writer, and the potential remains uncertain.

Conditions in this district considered favorable for formation of sedimentary uranium deposits are:

(1) Presence of a thick (up to 9,000 feet) nonmarine arkosic sandstone unit containing carbonaceous material (Kushtaka and Kulthieth formations).

(2) Presence of tuffaceous material in the section above the arkosic sandstone, but the amount is not known (Brooks, 1908, p. 42; Miller, 1951, 1961a, c).

(3) Presence of pyrite and redbeds (Miller, 1951, 1961) although they are not abundant.

(4) Low-level radioactivity detected in beach sand concentrates, and a questionable 19 percent U assay from the Yakataga beach sands.

(5) Copper showing in outcrops and in placers.

Conditions of the sedimentary rocks in the district which are generally considered unfavorable for uranium concentration are:

(1) Strata are highly disturbed and steeply dipping.

(2) Induration has resulted in very low porosity of the sediments.

(3) Climate is very humid; average annual precipitation at Yakutat is 131.8 inches (Searby, 1968, p. 8).

(4) Large uranium source areas are not known.

(5) Erosion has removed an unknown amount of Tertiary sediments.

In summary it appears that the region has not been adequately prospected and that the nonmarine sections in the Bering coal field, Yakataga, and Lituya Bay areas should be surveyed radiometrically. While conditions do not suggest a highly favorable environment for uranium concentration, it is conceivable that uranium could have been precipitated in the sandstones shortly after their deposition and before being tectonically disturbed. Logging of drill holes and water analyses for uranium might be required to assess the possibilities because any uranium originally present could have been leached out of the surficial rocks.

PRINCE WILLIAM SOUND

Prince William Sound is the northernmost embayment of the Gulf of Alaska (fig. 12) and is separated from the open ocean by a series of islands. The district is about 150 miles across from the Kenai Mountains on the west to the Copper River to the east. The entire coastal area and nearby islands are part of the rugged Chugach Mountains. The district is well known for its gold and copper mines, glaciers, and alpine scenery.

Sedimentary Rocks

The Prince William Sound area is underlain by many thousands of feet of complexly deformed and mildly metamorphosed euogeosynclinal clastic and volcanic rocks, which have been described by Moffit (1954, p. 242-275).

The sediments have been divided into two groups: the older was named the Valdez Group, and the younger the Orca Group. Because of the scarcity of fossils the ages of these rocks were long regarded as uncertain but were thought to be Mesozoic. Recent fossil finds have established that the upper part of the sequence, the Orca Group, is Tertiary, and that the Valdez is Jurassic to Cretaceous (Plafker and MacNeil, 1966). Their distribution is shown on figure 12.

The Valdez Group is dominantly graywacke, argillite, mud-derived slate, and arkosic sandstones. The beds also include minor interstratified conglomerates and impure limestone and locally shows thin, cyclic bedding. The thicknesses vary to many thousands of feet. The Valdez beds have been intruded by large, irregular stocks of both acidic and basic compositions, and numerous dikes and sills, dominantly diorite and aplite. The Valdez Group is somewhat more metamorphosed than the Orca Group and is schistose in places. Quartz veins are abundant. The source locality for the Valdez Group is not known but it apparently included nearby sedimentary and igneous rocks.

The Orca Group, which occurs mostly in the eastern part of the Prince William Sound area, consists mostly of several thousand feet of folded and faulted slate and graywacke, and includes an abundance of altered basic intrusive and extrusive rocks, now classed as greenstone. The group includes some conglomerate and limestone, and abundant arkosic sandstones are characteristic of the upper portion of the group. Minor tuffaceous and carbonaceous materials are present. Pillow lavas indicate that underwater extrusions were common.

Tertiary coal-bearing and petroliferous beds comparable to those in the Katalla area are not present in the Prince William Sound district.

Igneous Rocks

Several plutons in the Prince William Sound area are a part of the belt of granitic intrusives which rims the Pacific Ocean basin in Alaska. Their distribution is shown in figure 12. Compositions and textures of the intrusive rocks show a wide variation; quartz diorite, granodiorite, and quartz monzonite are present. Lanphere (1966) reported that the potassium-argon ages of four plutons in the western part of the Prince William Sound area range from 34.4 to 36.6 m.y., which indicates emplacement during early Oligocene.

Structure

A major period of orogeny that probably climaxed in late Eocene or early Oligocene deformed the sediments and resulted in the emplacement of the granitic stocks and important mineral deposits. The beds were tightly folded and their dips are frequently vertical. A complex pattern of linear features

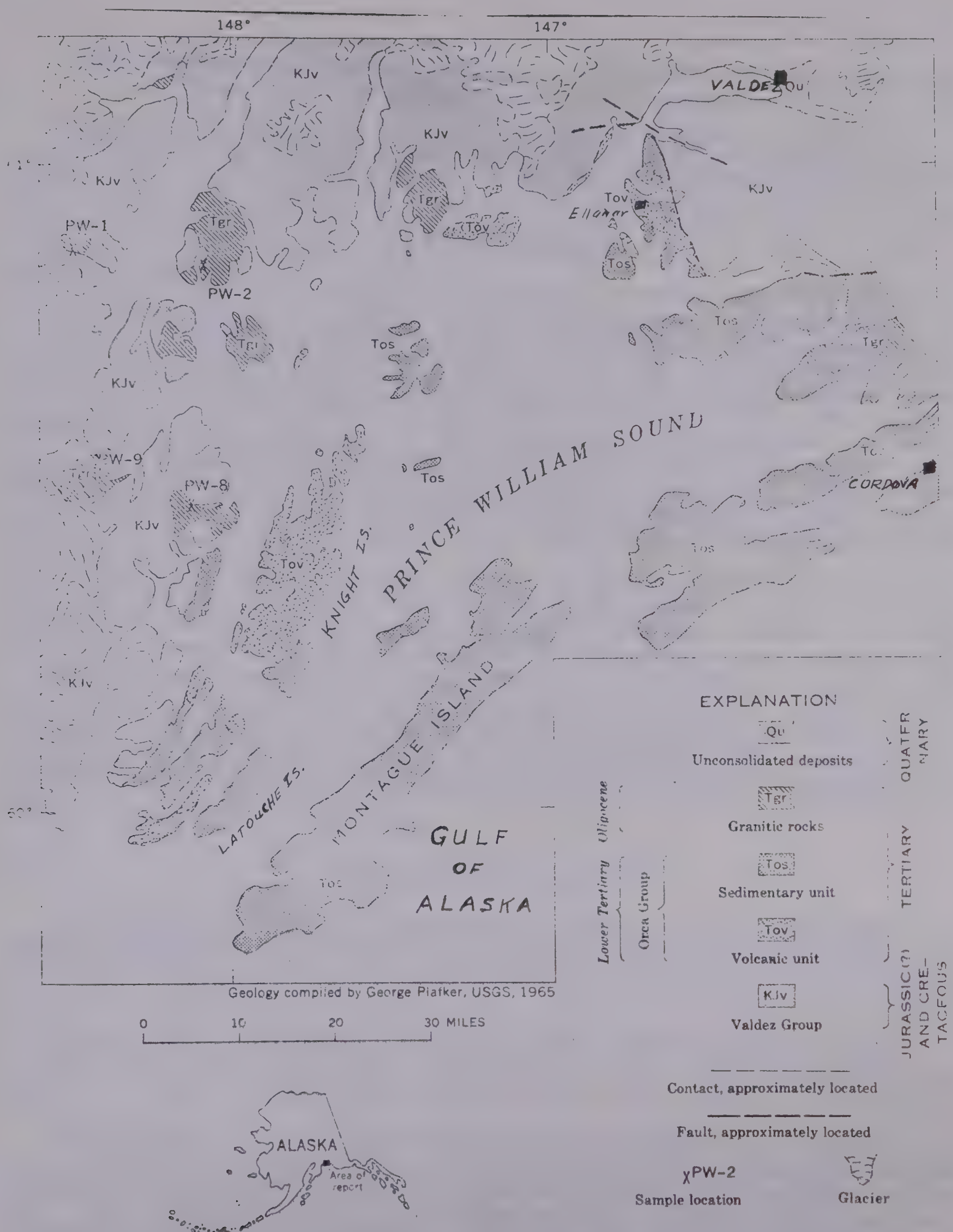


Figure 12. Generalized geologic map of part of the Prince William Sound region, Alaska, showing location of dated samples. (Source: Plafker and MacNeil, 1966.)

mapped by Condon (1965) are believed to represent faults, shear zones, and joints, which may have been critical to localization of ore deposits.

The epicenter of the great Alaskan earthquake of 1964 was under Prince William Sound, indicating that the region is still tectonically active.

Economic Geology

Sixty-three metalliferous lode deposits in the Prince William Sound district are listed by Berg and Cobb (1967, p. 66-68). Important copper and gold production began in about 1897. Copper deposits in particular are present throughout the district, but the major mines were centered in two areas: the northeastern area, which includes the deposits along the west side of the Landlocked Bay thrust fault near Ellamar, and the southeastern area, which includes the lodes on Latouche and Knight Islands. The Beatson Mine on Latouche Island was once the second largest copper producer in the state; it is no longer active. Silver was recovered as a byproduct at various mines, and iron, arsenic, lead, zinc, antimony, and nickel were found but were not recovered (Cobb, 1969; Cobb and Matson, 1969).

The district produced about 214 million pounds of copper up to 1930 (Moffit and Fellows, 1950, p. 50). The principal ore mineral was chalcopyrite, but pyrite, arsenopyrite, galena, sphalerite, cubanite, and chalcocite(?) were also present. Most of the copper is in the greenstone or in slate and graywacke adjacent to greenstone, with which it apparently is genetically related.

At least 136,000 fine ounces of gold was produced prior to World War II. The auriferous lodes are most abundant in the northern part of the district. Besides gold the ores contained silver, pyrite, galena, chalcopyrite, arsenopyrite, sphalerite, pyrrhotite, and stibnite.

Radioactivity Investigations

Moxham (1952, p. 4, 5) made a reconnaissance radiometric study in the mining area near Valdez. Concentrates from eight samples from various streams produced values between 0.002 and 0.005 percent eU. None was considered unusual.

Wedow, White, and Moxham (1951, p. 110, 111) mention that fluorite has been reported in quartz veins on Passage Canal along with sulfide ores, and an occurrence of hematite was noted on Hinchinbrook Island.

Radiometric reconnaissance tests were conducted in the Prince William Sound area by Wedow and others (1952, p. 13). Representative samples of various lodes, granitic bodies, and adjacent contact zones generally contained less than 0.001 percent eU. The maximum eU found was 0.003 percent from granitic rock at Ester Island and Trap Bay, probably due to common accessory minerals. Tests on the hematite on Hinchinbrook Island produced up to 0.003 percent eU.

Discussion

Conditions which are considered unfavorable for sedimentary uranium deposits prevail in the Prince William Sound district: (1) a predominantly marine origin of both the Mesozoic and Tertiary sediments, (2) tight folding of the beds, and a loss of porosity, (3) low eU values obtained from samples from the district during reconnaissance surveys, and (4) high annual rainfall, reported to be as much as 200 inches, which would tend to leach out any near-surface uranium occurrences.

While the general character of the Tertiary Orca Group does not seem suitable for uranium deposits, the arkosic and tuffaceous units may warrant testing. The writer is unaware of this having been done. Moffit (1954, p. 250-252, 258) mentions arkosic beds at Orca Bay and other locations.

The mineral assemblages of the lode deposits and the presence of Tertiary granitic intrusives suggest that the area is more favorable for vein uranium than for sedimentary types. Reports of radioactivity tests are not encouraging, but they are based on brief reconnaissance surveys, and additional prospecting of the contact zones around the more alkalic granitic intrusives is suggested.

KENAI PENINSULA

The Kenai Peninsula separates the Cook Inlet from the Gulf of Alaska. About 150 miles of coastal area between the southwestern tip of the peninsula and Montague Strait at the entrance to Prince William Sound is included with the Gulf of Alaska Province (fig. 13). This district is bordered by the southeastern flanks of the rugged Kenai and Chugach Mountains, which rise abruptly from the coast.

Sedimentary Rocks

Tertiary sedimentary rocks are present on the southeastern side of Kenai Peninsula in only one small area, on Resurrection Peninsula, which lies on the east side of Resurrection Bay off of Blying Sound (King, 1969). The Tertiary rocks are predominantly greenstones, tuffs, graywackes, and slates and may be equivalent to the Orca group in the Prince William Sound district. A detailed description of the rocks on Resurrection Peninsula does not seem to be available, but the area is known to contain a number of lode copper prospects (Martin, Johnson, and Grant, 1915, p. 234-236).

The remaining coastal area is composed of thousands of feet of metamorphosed Late Cretaceous geosynclinal sediments, mostly argillites and slates, with minor poorly sorted graywacke sandstone, quartzite, chert, and conglomerate. These rocks have been intensely folded and faulted (Miller, Payne, and Gryc, 1959, p. 20-21). Richter (1970, p. B4) reported a stretched pebble conglomerate up to 100 feet thick at Nuka Bay containing clasts that are reworked graywacke and siltstone fragments.

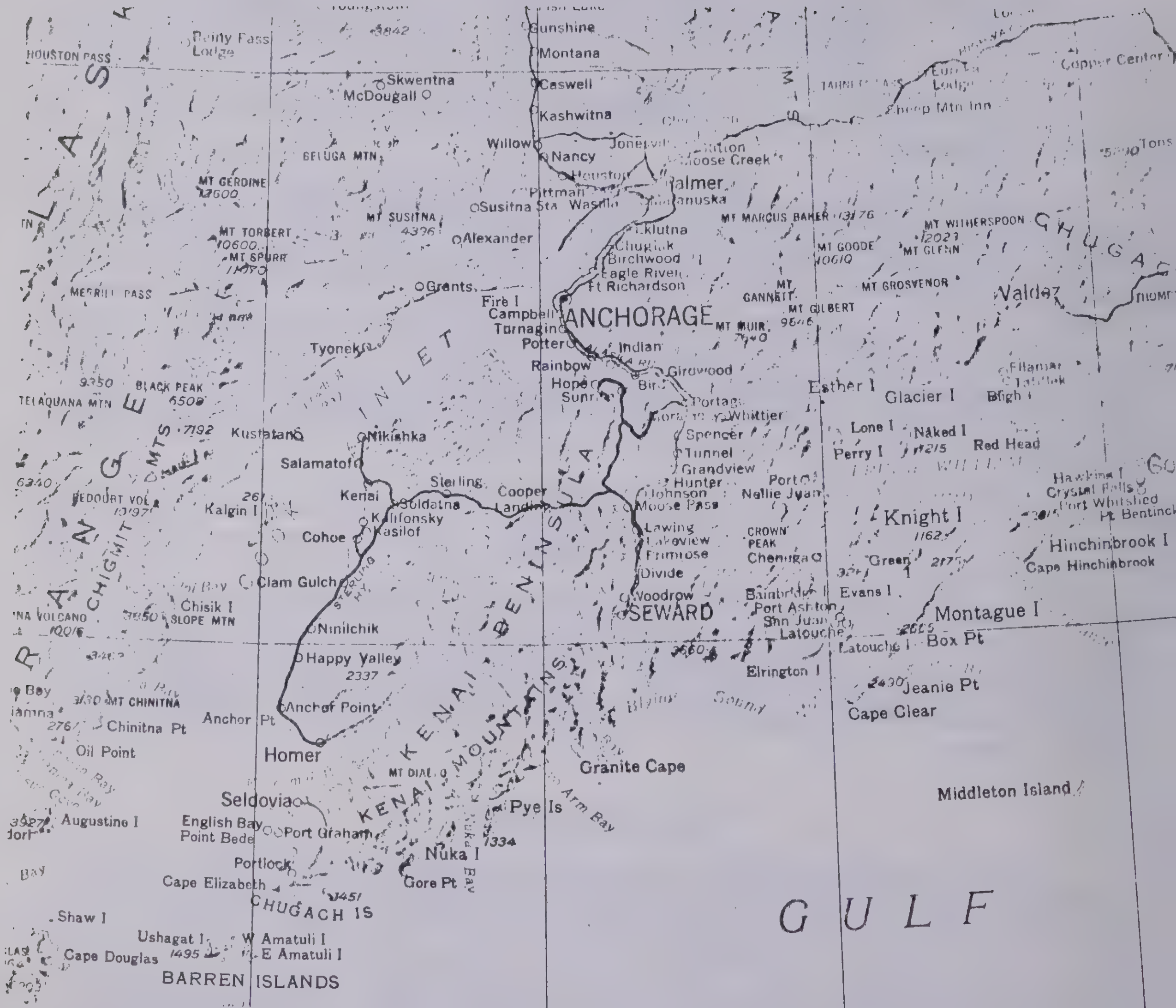


Figure 13. Index map, Kenai Peninsula.

Igneous Rocks

The intrusive rocks in the district are both basic and acidic. Two large granitic masses are present: one forms the islands in the mouth of Resurrection Bay, and one makes up the Pye Islands and part of the nearby coast. Scattered small dikes and sills cut the metamorphosed sediments.

Richter (1970, p. B4) described the dikes and sills in the Nuka Bay area as consisting of 50-60 percent sodic andesine, 10-20 percent potassium feldspar, 5-15 percent quartz, and 1-2 percent scattered opaque minerals. The intrusives cut the Cretaceous beds and are assumed to be Tertiary.

Structure

At the close of the Cretaceous or during Paleocene, the rocks in the district were uplifted and strongly folded, and minor faulting and jointing are conspicuous (Payne, 1955). Crystalline rocks were intruded during the orogeny.

Economic Geology

Lode prospects for gold, copper, iron, and chromium are scattered along the southeastern coast of the Kenai Peninsula, but few have had any significant development work. Gold-quartz veins are fairly common. These contain considerable arsenopyrite and lesser amounts of chalcopyrite, pyrite, pyrrhotite, sphalerite, and galena (Martin, Johnson, and Grant, 1915, p. 228-237; Richter, 1970, p. B6). Gold production for the Nuka Bay area has been estimated to have been $166,000 (Richter, 1970, p. B6). A number of copper prospects are known on Resurrection Peninsula (Martin, Johnson, and Grant, 1915, p. 177) and small amounts of silver have been reported in several localities. Smith (1938, p. 27) reported the presence of tetrahedrite at Nuka Bay.

The distribution of metallic mineral deposits on the southeastern side of Seward Peninsula is shown on the resources maps by Cobb (1972a) and Cobb and Richter (1972).

Radioactivity Investigations

The silver-bearing galena-pyrite-arsenopyrite-quartz fissure veins at Nuka Bay were examined in 1951 by U.S. Geological Survey geologists (White and others, 1952, p. 10, 12). No radioactive material containing over 0.002 percent eU was found and it was concluded that the lode deposits in the area are not favorable for the occurrence of high-grade uranium ores.

Discussion

The southeastern coastal part of the Kenai Peninsula does not seem to contain sedimentary rocks with favorable characteristics for uranium deposits. Except for about 30 square miles on Resurrection Peninsula underlain by Tertiary sediments and greenstone, the rocks are Cretaceous age, primarily of

marine origin, intensely deformed, and considerably metamorphosed. The small area of Tertiary rocks includes volcanic tuffs, but in unknown quantities. The Tertiary greenstones contain a number of small copper deposits, but the overall lithology and mineralization offer little encouragement to the uranium explorationist.

Two sites, however, are suggested for examination. Hematite is present as reddish jasperoid material in greenstone at the head of Port Dick, southwest of Nuka Bay, and in greenstone on Resurrection Peninsula (Martin, Johnson, and Grant, 1915, p. 229, 234, 237). This material may not have been tested for radioactivity. An abundance of pyrite was reported in graywacke beds south of Seward (Martin, Johnson, and Grant, 1915, p. 217). This rock should be examined.

KODIAK ISLAND GROUP

The Kodiak Island group forms the western end of the Gulf of Alaska. The island group is believed to be geologically a continuation of the Kenai Peninsula; the rocks seem to correlate and the structure is similar. The Kodiak Islands, including the Trinity Islands, extend for a distance of 177 miles, occupy about 4,900 square miles, and at the broadest point are about 67 miles wide. Kodiak Island is by far the largest of the group. It contains rugged mountain areas with glaciated peaks rising to over 4,400 feet above sea level. The coasts are characterized by intricate shorelines and numerous branching bays. The average annual rainfall is over 60 inches, and dense brush makes travel very difficult. Geologic mapping is sketchy and of a reconnaissance nature over much of the area, and records of mining and exploration are meager. Bedrock exposures are scarce, except along the coasts.

The axis of the Cretaceous Chugach Mountains geosyncline trends northeast along the long axis of the Kodiak Island group. Uplift and erosion of the trough began during Paleocene time and has continued to the present (Payne, 1955). The country rocks that occupy most of the central portion of the island group consist mostly of Jurassic and Cretaceous metasediments and greenstone. These rocks are cut by numerous early Tertiary intrusives, and the backbone of Kodiak Island is an elongated quartz diorite mass extending the length of the island.

Small areas of poorly consolidated Tertiary sediments lie along the southeastern margin of the island and may extend beneath the Pacific Ocean (fig. 14). Tertiary sediments also occur on Chirikof Island about 50 miles southwest of the Kodiak group.

This review of the Kodiak Islands is generally limited to the eastern and southeastern margins which border the Gulf of Alaska. The Permian, Triassic, and Jurassic rocks are not present on the southeastern side of the islands and will not be discussed.

Sedimentary Rocks

The most recent geologic mapping in the district is the USGS Preliminary Geologic Map of the Kodiak Island and Vicinity (Moore, 1967). However, no descriptions of the stratigraphic units accompany the map, so an earlier report

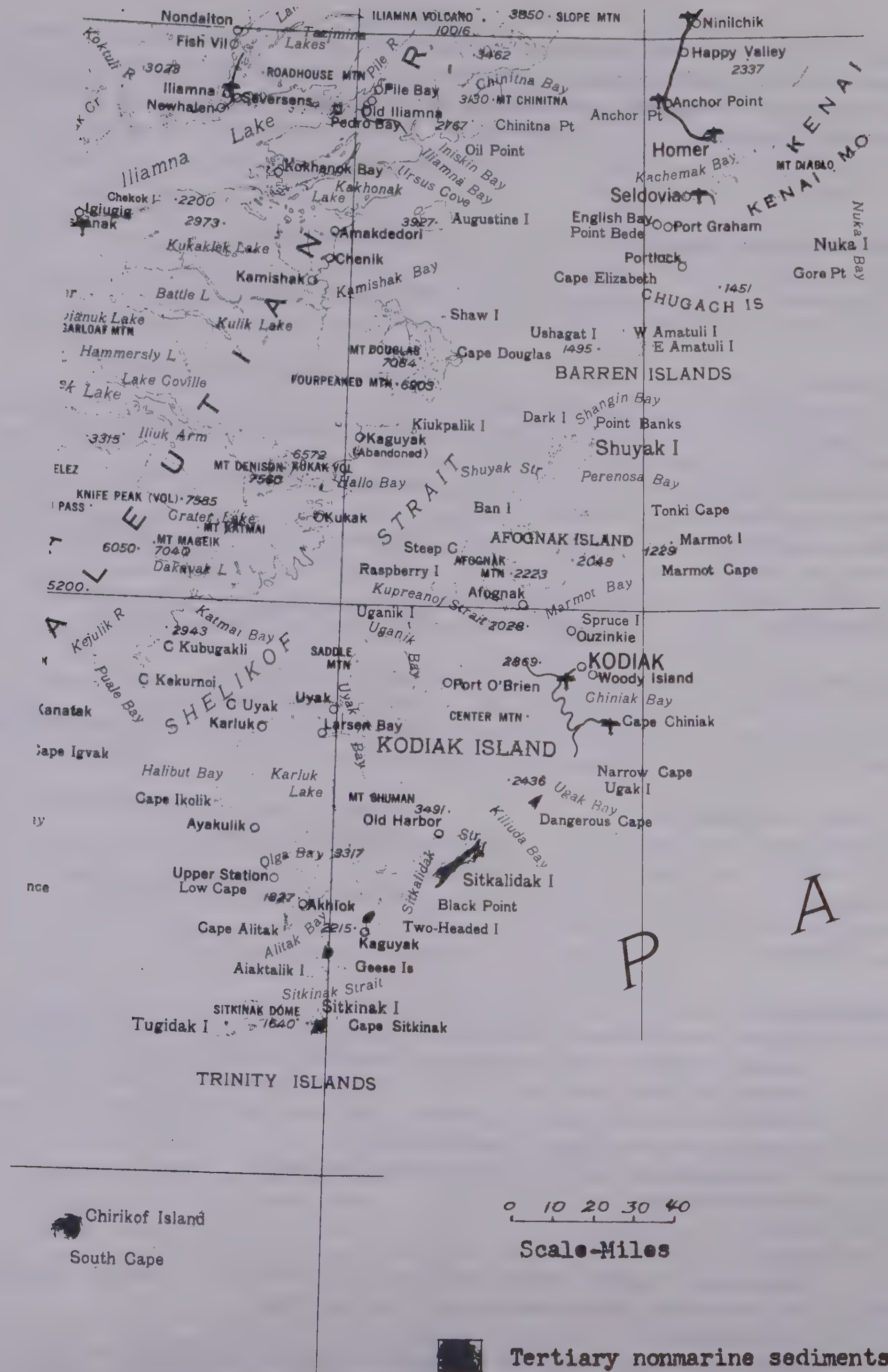


Figure 14. Index map, Kodiak Island group.

by Capps (1937) has been employed for most of the lithology and mineralogy. There is a slight difference in the age of the nonmarine Tertiary unit in the two publications. The following descriptions compare the stratigraphy given in the two publications.

Moore, 1967:

Pliocene and Recent	Surficial deposits
Pliocene	Marine sedimentary rocks and volcanic rocks
Miocene	Marine sedimentary rocks
Oligocene	Continental sedimentary rocks
Eocene-Oligocene	Marine sedimentary rocks
Paleocene-Eocene	Volcanic and marine sedimentary rocks and quartz diorite
Cretaceous	Marine sedimentary rocks
Jurassic	Naknek Formation Shelikof Formation Lower and Middle Jurassic sedimentary rocks
Triassic-Jurassic	Volcanic and marine sedimentary rocks Ultramafic rocks
Permian	Marine sedimentary rocks

Capps, 1937:

Quaternary:

Gravel, sand, and silt of the present streams; beach deposits of sand, gravel shingle, and boulders; bars and spits; tidal flats; talus accumulations; peat and impure organic deposits; soil and rock-disintegration products in place; terraces and bench gravel, some of glaciofluvial origin; volcanic ash.

Glacial deposits of Pleistocene glaciers.

Unconformity.

Tertiary:

Moderately consolidated and gently folded buff marine sandstones of Narrow Point, of Miocene or Pliocene age.

Unconformity.

Sandstones, shales, and conglomerates of southeastern coast of Kodiak Island and adjacent islands, in general highly inclined and locally greatly folded, crumpled, and distorted. Contain carbonized plant remains and coal seams. Of probable Eocene age. These rocks also include massive, dense mottled sandstones of Kalsin and Ugak Bays and Port Hobron.

Unconformity.

Mesozoic:

Granite intrusives as irregular masses, stocks, dikes, and sills, cutting youngest Mesozoic sediments. Of late Mesozoic or early Tertiary age. Graywacke, slate, and conglomerate, the dominant formation throughout the Kodiak group of islands. Probably Cretaceous and older.

Unconformity.

Greenstone schist, knotty schist of greenstone and associated sedimentary rocks; ellipsoidal greenstone; crystalline limestone; contorted cherts and argillaceous and sedimentary rocks; volcanic tuff; mica schist. Mainly of early Mesozoic age, though probably continuing some older materials.

The dominant rock group in the Kodiak Island group is the Cretaceous graywacke-slate-conglomerate sequence which is separated from the coastal Tertiary belt along the southeastern edge of the islands by a northeast-trending down-to-the-coast normal fault that extends the length of Kodiak Island. The most abundant Cretaceous lithologies are thin-bedded slate and graywacke. Carbonaceous material contributes to the dark color to the graywackes (Capps, 1937, p. 142). Conglomerate, grit, limy slate, and altered tuff form a very small portion of the sequence. Many small acidic intrusives and quartz veinlets penetrate the sediments. The total thickness of the sequence has not been determined but it is many thousands of feet.

The graywacke 10 miles northwest of the town of Kodiak was described by Seitz (1963, p. 74) as a hard, tough rock that in places resembles a quartzite. It contains largely quartz, feldspar, biotite, and pyroxene with some pyrite, arsenopyrite, and pyrrhotite. The slate was found to be exceedingly fine-grained and fissile.

The conglomerate beds in the Cretaceous are intraformational and form only a small fraction of the sequence. Individual beds range from 2 to 15 feet, and clasts range from pebble to pea size. The pebbles consist of argillite, quartz, chert, and siliceous dike rocks, but little or no granitic material is present. Distortion and shearing of the beds illustrate strong regional deformation.

Altered volcanic tuff has been reported only at a location 4 miles northwest of the head of Viekhoda Bay, on the western side of Kodiak Island, and not within the district under consideration here.

The Tertiary rocks along the southeast margin of Kodiak Island and on Sitkinak Island were divided into two groups by Capps: the older consisting of Eocene freshwater sandstone, shale, and conglomerate; and a younger Miocene-to-Pliocene sequence of marine sandstones. Mapping by Moore indicated that the nonmarine portion of the Tertiary rocks is much more limited than believed by Capps, underlying about 55 square miles, mostly on Sitkalidak and Sitkinak Islands.

The thickness of the nonmarine section, according to Capps, is not known, but may be several thousand feet. A measured interval, representing a portion of the sequence, is reproduced below from Capps (1937, p. 150). It was not possible to tell if the section is normal or inverted.

Section on east shore of Tanginak Bay, Sitkalidak Island

	Feet
Sandstone	250
Concealed	200
Sandstone and conglomerate	200
Conglomerate	100
Contorted sandstone and shale	100
Thin-bedded sandstone and shale	75
Mildly contorted shale with some sandstone	180
Thin-bedded sandstone and shale	100
Highly contorted shale	180
Thin-bedded sandstone and shale	270
Contorted shale	90
Thin-bedded sandstone and shale	30
Mainly shale, with some sandstone and grit	300
Total	2,075

The continental sediments were thought by Capps to lie unconformably upon the Cretaceous slate-graywacke group and to be overlain with probable unconformity by marine Miocene or Pliocene sandstones. The nonmarine sandstones were found in thin section to consist of subangular to rounded grains of quartz, orthoclase, microperthite, and biotite, largely derived from granitic rocks. Some sedimentary rock fragments are also present. Ripple marks, coaly plant fragments, and small nodule and lenticular seams of coal up to 1 inch thick were considered characteristic of the sandstones. The conglomerates contain pebbles of both sedimentary and granitic origins. Capps (1937, p. 151) also noted that the basal portion of the sandstone had a greenish cast, was fractured, and that the fractures were filled with thin gray-white filaments of carbonate and zeolites. The source of the green color is not known, but the nearness of a major fault may account for the fracturing.

The marine Miocene sandstone of Capps was found only along the shore at the entrance to Ugak Bay, where it occupies 4 square miles. The sandstone here was described as a fine-grained, indurated, gray to buff rock containing a 1-foot bed of fossil shells. The sandstone is largely quartz, with feldspar, ferromagnesia minerals, fragments of slate, and some clayey material. It is mildly folded, strikes northwest, and dips from 15 to 20 degrees. About 1,000 feet of the section is exposed. Moore mapped marine Pliocene sediments on Tugidak Island, in the Trinity Islands, but no description of these is available.

Volcanic ash from the 1912 eruption of Mt. Katmai formed a thick blanket over much of the Kodiak Islands, but the material has since largely been washed into stream valleys and bays, where it is still present.

Little information was located concerning Chirikof Island but mapping by Moore indicates it is largely underlain by nonmarine Tertiary sediments. This is a small island, 11 miles long, located 50 miles southwest of the Trinity Islands. Burk (1965, p. 66) states:

> *Samples from the highly deformed rocks of Chirikof Island are gray to green, dense, muscovite-rich sandstones, and dark siltstones*

and shales. These appear to be similar to the early Tertiary strata of Kodiak and Sitkinak Islands; it is unlikely that older beds of the slate and graywacke belt are exposed.

The description suggests that Chirikof Island may be at least partially underlain with nonmarine sediments and should be considered if Tertiary beds in the region are investigated for uranium.

Intrusive Rocks

The sediments and metasediments of Kodiak Island are cut by numerous early Tertiary intrusive bodies. The largest is an elongated gray quartz diorite mass that extends the length of the island for 68 miles and is up to 12 miles wide (Moore, 1967). This mass forms peaks ranging between 3,000 and 4,000 feet above sea level. It is coarse to medium-grained and characteristically consists of sericitized plagioclase, quartz, and biotite. Many smaller outlying intrusions of dioritic to granitic composition are present, and acidic dikes with associated quartz veins are common. Gabbro was noted on the southeast side of Kodiak Island northeast of Ugak Bay. Ultramafic intrusives are present on the west side of Kodiak Island, but these are outside the district considered here. Although granitic rocks occupy a considerable part of Kodiak Island, they are somewhat scarce along the coast in the Tertiary province. Moore shows four small quartz diorite masses north of the entrance to Ugak Bay and one near the head of Aliulik Peninsula. Dikes and sills are more common. Thin sections of several dikes (Capps, 1937, p. 157) showed them to include microquartz diorite, granodiorite, muscovite granite, rhyolite, sodic rhyolite, and rhyolite porphyry.

The compositions of six granodiorite samples from the Sharatin Bay—Anton Larsen Bay area, 10 miles northeast of the town of Kodiak, are given from Rose and Richter (1967, p. 2):

Medium to coarse-grained muscovite-biotite granodiorite crops out along the east shore of Sharatin Bay, and according to Capps (1937) forms a pluton about three miles long and a mile wide, as indicated on the map (figure 1). The composition of a typical specimen (sample KO-5) is shown in Table 1. The biotite contains pleochroic halos around tiny inclusions of an unknown mineral.

*Table 1. Composition of granitic rocks**

	KO-5	6E-15	6E-48	6E-57	6E-20	6E-47
Quartz	25	25	30	20	15	20
Plagioclase	51	58	48	64	60	55
% An	5-30	10-25	10-35	10-15	0-5	0-5
Orthoclase	15	10	15	10	10	15
Biotite	7	4	5	5		3
Muscovite	2	3	2	1	15	7
Magnetite				tr.		
Apatite	tr.		tr.			
Pyrite	tr.	tr.				

**Composition by estimates in thin sections.*

Table 1. (continued)

KO-5	*Sharatin Bay granodiorite, 1/3 mile east of triangulation point Dahl.*
6E-15	*Granodiorite of Anton Larsen Bay, west side of Peninsula north of the end of the road.*
6E-48	*Granodiorite of Anton Larsen Bay, 1/4 mile north of triangulation point Anton on large island in Anton Larsen Bay.*
6E-57	*Granodiorite of Anton Larsen Bay, on west shore of bay at the mouth.*
6E-20	*Fine-grained leuco-granodiorite dike from Sharatin Bay at three-pillar Point.*
6E-47	*Leuco-granodiorite dike, 0.6 miles northwest of triangulation point Anton on island in Anton Larsen Bay.*

Structure

The structural trends of the bedded rocks, major faults, and large intrusives are northeast, parallel to the long axis of Kodiak Island and the Kenai Peninsula. Bedding dips are generally westerly. A normal southeast-dipping fault along the southeastern side of Kodiak Island, about 8 miles from the coast, is a major feature that separates the Tertiary sediments along the edge of the island from the Cretaceous sediments in the interior. Many lesser faults have the same general trend. The Cretaceous greenstone-schist rocks are folded and faulted, and in places contorted and schistose. The Tertiary beds are also highly disturbed and show severe alteration, particularly close to the major faults.

Continuing earthquakes and the raised coastal plains on Kodiak Island indicate recent movement. Strong earthquakes in 1912, supposedly related to the Mt. Katmai eruption, disturbed the bluffs, displaced adjacent blocks of ground up to 3 feet, and opened cracks as wide as 1 foot. The Good Friday earthquake of 1964 caused up to 5-1/2 feet of subsidence at the northern end of Kodiak Island.

Economic Geology

The only mineral production of any consequence to date on Kodiak Island has been from gold placers in the beach sands along the northwest and southwest shores. The deposits have been small, transitory occurrences formed by wave action which concentrated gold derived from Quaternary gravels. A number of lode prospects have been worked, but none have been economically successful.

A group of gold-lode claims is located 3 miles northwest of the village of Old Harbor on the southeast coast of Kodiak Island near the head of Barling Bay. The largest lode consists of a zone of massive quartz trending northeast and reportedly extending for several miles through slate and graywacke country rock (Capps, 1937, p. 181, 182). Vein material was reported to have assayed several dollars a ton in gold and silver. The only sulfides noted were arsenopyrite and pyrite.

A gold-quartz lode on Kizhuyak Point, near the northeastern end of Kodiak Island in Marmot Bay, has been known since 1906. The white quartz vein, called

the Woman's Bay Lode, fills a fracture in a diorite mass. Visible metallic minerals reported include arsenopyrite, pyrite, chalcopyrite, sphalerite, galena, and oxidation products. The lode contained small gold and silver values (Capps, 1937, p. 178, 179).

The Old Harbor copper lode at the northwest side of Sitkalidak Island, off the southeast coast of Kodiak Island, consists of a 2,500-foot-long sulfide-bearing shear zone at the contact between a gabbro sill and slate graywacke. Mineralization consists of disseminated pyrrhotite, pyrite, and sparce chalcopyrite. In places the sulfides are concentrated into small masses (Berg and Cobb, 1967, p. 87, 88). Despite assays yielding up to 5.52 percent copper, the deposit was considered uneconomical when examined by the U.S. Bureau of Mines in 1944.

Tungsten occurrences about 10 miles north of the town of Kodiak near the head of Anton Larsen Bay have been investigated by several mining companies. Scheelite was found disseminated as fine veinlets and grains in quartz zones in graywacke and as thin coatings in quartz veins and fractures. Arsenopyrite, chalcopyrite, and pyrite accompany the scheelite in small to trace amounts. Assays listed show WO_3 from 0.06 to 1.75 percent. Nearby gold-quartz veins assayed up to 0.28 ounces of gold and 3.50 ounces of silver per ton (Rose and Richter, 1967, p. 10).

Coal, while not of economic importance, is present in thin seams a few inches thick in the Tertiary sediments on the eastern side of Kodiak Island; and thicker beds are present on Sitkinak Island, where one short seam was reported to be 10 to 12 feet thick (Martin, 1913, p. 136). Tertiary marine sediments may extend offshore under the Pacific, and they may eventually be found to contain petroleum.

Radioactivity Investigations

A survey of the literature indicates that there have been almost no uranium investigations by government agencies in the Kodiak Island group. Only two reports mention radioactivity in the area. Uranium was once rumored (Wedow, White, and Moxham, 1951, p. 109) to occur in a lode deposit on Raspberry Island, in the northeastern part of the island group, but no information is available. A uraniferous sample stated to have been found just outside the town of Kodiak was submitted by prospectors in 1953. The sample containing meta-autunite and metatyuyamunite reportedly assayed over 1 percent uranium. A field check failed to reveal any significant radioactivity (Wedow, 1956, p. 33, 35).

Discussion

The lack of radiometric investigations and a deficiency of geologic data make it difficult to assess the uranium potential of this district. The concentration of claims in locations easily accessible by water transportation suggests that nearly all prospecting has been confined to these areas and that less than 20 percent of Kodiak Island has been adequately prospected (McGee, 1972, p. 6). The two early reports of radioactivity in the area seem to be of questionable reliability.

The nonmarine Tertiary sediments are near the coast and offer the most obvious target for uranium exploration, though they are quite limited in extent. The fact these rocks are largely of granitic origin and contain coaly material and zeolites (derived from volcanic ash?) increases their favorability.

Zones in the Cretaceous graywacke sequence containing carbonaceous material north of the town of Kodiak should be tested to determine if the carbon has precipitated uranium. The reported presence of quartz, feldspar, biotite, pyrite, arsenopyrite, and pyrrhotite of these rocks is also of interest. Porosity is now probably totally absent, but the locking up of uranium in the sediments prior to metamorphism is considered a possibility.

The mineralogy of the lode deposits in the district seems only moderately encouraging for uranium association, but minor quantities of silver and copper suggest that the lodes where these have been found should be tested.

The pleochroic halos noted by Rose and Richter (1967, p. 2) in biotite in the granodiorite at Sharatin Bay could be caused by radioactivity. It is known that uranium may be included in mica as fine particles of a relatively pure salt that produces pleochroic halos around the particles (DeMent and Drake, 1945, p. 295).

Broad targets are presented by the border areas of the many quartz diorite intrusives on Kodiak Island. The difficult accessibility of these areas indicates that the first phase of their investigation should probably be by airborne scintillometer.

MATANUSKA VALLEY

The Matanuska Valley extends northwestward from near the head of Cook Inlet for about 60 miles along the Matanuska River (fig. 15). The Glenn Highway bisects the valley, which separates the Chugach Mountains on the south from the Talkeetna Mountains on the north. Peaks in these ranges rise to elevations between 4,000 to 7,000 feet. The valley is about 10 miles wide at its mouth, near Moose Creek, and narrows as it proceeds upstream. The lower part of the valley is noted for its fine farms and for the Tertiary coal deposits that were mined on the northern side of the valley for about 50 years. Most mines are concentrated on Wishbone Hill, near Jonesville and Eska. Mining was discontinued in 1969 because of the conversion to natural gas by the military bases in the nearby Anchorage area. Average rainfall is 16 inches.

The Matanuska Valley is underlain by Tertiary and Mesozoic sediments which have been downfaulted between the two mountain ranges (Grantz, 1964, p. 13). The rocks to the north are part of the Talkeetna batholith, and those on the south are volcanic rocks of the Jurassic Talkeetna Formation (Barnes, 1962).

The lower part of the Matanuska Valley is the concern of this study because it contains Cretaceous and Tertiary sediments that have some of the characteristics of known uranium host rocks in the western states. Some of the sediments correlative with the lower Matanuska Valley beds are also present in the Cook Inlet basin and in the Copper River Basin, which is located to the northeast.

Figure 15. Index map, Matanuska Valley area.

Sedimentary Rocks

The lower Matanuska Valley is underlain by predominantly marine and nonmarine clastic sedimentary rocks that range in age from Lower Jurassic to Pleistocene. Altered volcanics of the Lower Jurassic Talkeetna Formation form the Chugach Mountains on the south and unconformably underlie the Cretaceous and Tertiary rocks of the valley floor. Middle and Upper Jurassic granitic rocks of the Talkeetna batholith form the Talkeetna Mountains that border the valley on the north.

The stratigraphy is summarized in table 1; and figure 16 shows the generalized geology of the Matanuska Valley and the extent of Tertiary sediments. The Lower Jurassic Talkeetna Formation, the Middle or Upper Jurassic Naknek Formation, a Cretaceous limestone, and the Lower and Upper Cretaceous Arkose Ridge Formation are grouped together as the map unit pKu. These are described briefly.

The Lower Jurassic Talkeetna Formation in the Chugach Mountains is predominantly volcanic and consists of tuff, breccia, and lava flows, generally altered to greenstone.

The Upper Jurassic Naknek Formation occupies only a very small area, possibly one-eighth of a square mile, on the south side of the valley. It consists of marine siltstone and shale with limestone concretions.

An unnamed limestone of Lower Crectaceous(?) age occurs in a narrow belt [illegible]th of Castle Mountain. It is unfossiliferous and consists of blue-gray to [illegible] cherty limestone.

The Arkose Ridge Formation for this report is described as Lower and Upper(?) Cretaceous age. The formation is now thought to be early Tertiary and correlative with the Chickaloon Formation (Kirschner and Lyon, 1973, p. 401 and fig. 9). The Arkose Ridge Formation consists of at least 2,000 feet of indurated arkose, shale, and conglomerate of continental origin. It occurs along the northern border of the Matanuska Valley, where it is in sedimentary contact with the Talkeetna batholith and is in thrust contact with the younger formations in the valley. The width of the outcrop area as mapped by Barnes (1962) varies from less than 1/4 mile to about 3 miles. Plant fossils are abundant, but no coal beds have been reported. The Arkose Ridge assemblege has been described by Martin and Katz (1912, p. 40):

> *The rocks exposed in the ridge north of Moose Creek are principally arkose, with a few beds of shale. The arkose is fine grained and conglomeratic in places, but the conglomeratic feature nowhere predominates. The rocks have a dark-brown to gray color and contain all the essential constituents of granite. Quartz, feldspar, hornblende, biotite, and chlorite can be easily recognized. Locally the feldspar is much kaolinized. The chlorite gives the whole rock in places a greenish tinge. Much of the arkose somewhat resembles an igneous rock. Some of it is so much like granite in appearance that its sedimentary character is recognizable only by a few rounded pebbles and carbonized plant remains. On the other hand, the arkose grades into conglomerate so that no definite line can be drawn between them.*

Table 1. Stratigraphy near the lower end of the Matanuska Valley
(Source: Alaska Geological Society Guidebook, 1964.)

The following tabulation of the stratigraphic section of the Wishbone Hill District is taken from Barnes and Payne (1956) with modifications based on later work:

Age	Formation	Character	Thickness (feet)
Quaternary		Alluvium, terrace gravels, and moraine deposits	0 - 150+
	Unconformity	-	-
	Tsadaka Formation	Coarse conglomerate, sandstone, siltstone	700+
Tertiary	Unconformity	-	-
	Wishbone Formation	Medium to fine-grained conglomerate, sandstone, and minor claystone	2,000
	Chickaloon Formation	Interbedded claystone, siltstone, sandstone and coal	5,000+
	Unconformity	-	-
Upper & Middle Cretaceous	Matanuska Formation	Shale and sandstone	4,000+
Middle(?) & Lower Cretaceous(?)	Arkose Ridge Formation	Arkose, conglomerate, and shale	2,000+

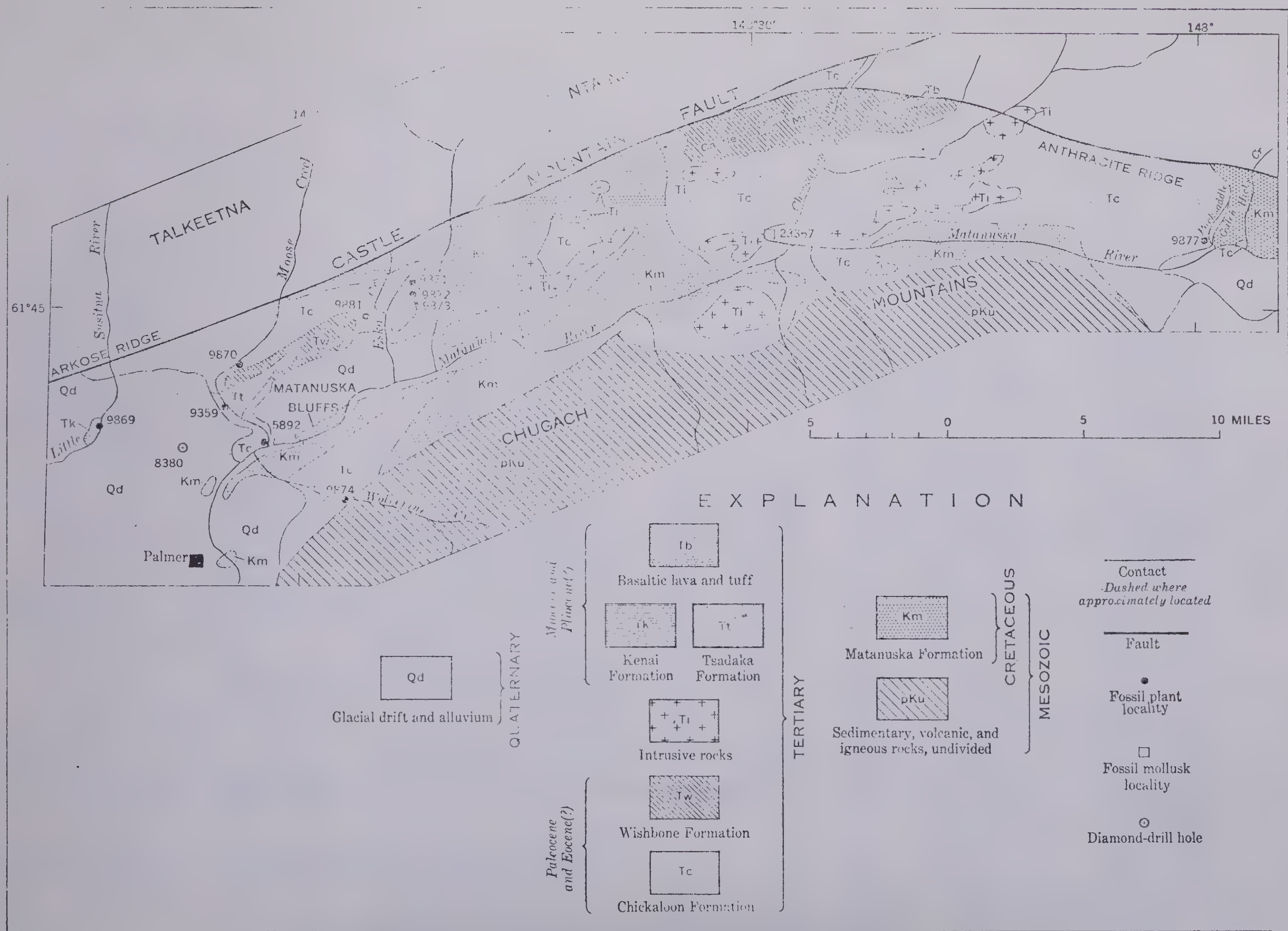


Figure 16. Generalized geologic map of the Matanuska Valley showing approximate extent of Tertiary sedimentary rocks and localities of fossil plants and mollusks. Modified from Capps (1927), Grantz and Jones (1960), Barnes and Payne (1956), and Barnes (1962a).

The exposures on the northern slope of the ridge (see Pl. VIII) show a thickness of over 1,500 feet of bedded rocks with no faulting. The outcrops on the crest of the ridge consist in some places of cross-bedded granitic arkose and in others of fine-grained conglomeratic arkose with small amounts of sandy shales and micaceous sandstones.

The conglomerates seem to be best developed north of Castle Mountain, where they are faulted against the Eska conglomerate, giving an excellent opportunity for the recognition of the essential lithologic characteristics of each formation. The following is a description of beds exposed in the creek entering Chickaloon River from the west a mile above the Government bridge. This creek emerges at an elevation of about 1,500 feet from a gorge with overhanging walls of sandstone and conglomerate. The conglomerate is the fine-pebble, well-indurated kind seen in Doone Creek north of Castle Mountain. The pebbles are mostly under 1 inch, though a few are 2 or 3 inches in greatest dimension, and are mostly of quartz and dark quartzite, the latter most abundant. They are not well rounded and are set in a matrix of fine conglomerate or coarse grit. The sandstone is more indurated than that of the Chickaloon formation and resembles more closely some of the sandstones of the Upper Cretaceous.

The Matanuska Formation consists of at least 4,000 feet of predominantly marine sediments which were assigned to the Lower and Upper Cretaceous by Grantz (1964). The character of the formation as a whole does not seem to have been described in detail, but generally it is composed of clay, silt, poorly sorted sandstone, and conglomerate and mixtures of these in varying proportions. Micaceous minerals, carbonaceous flakes, and fossil plant fragments are abundant in some beds. A few thin coaly seamlets are present. Clasts of the conglomerates consist of granitic, volcanic, chert, and quartz fragments.

The lower half of the formation is nearly all shale, and the upper half is interbedded shale and sandstone. Plant fossils at the lower extremity of the valley indicate that part of the formation (probably the upper part) is of continental or nearshore origin. The geanticlinal areas apparently supplied the volcanic and plutonic debris that constitute the bulk of the sediments.

The Matanuska Formation rests unconformably on Lower Jurassic volcanic rocks on the south side of the valley. The lower part is correlative with the nonmarine Arkose Ridge Formation, but the relation to the overlying Chickaloon Formation is not clear (Grantz, 1964, p. I 13). The formation is exposed over more than one third of the valley and is of special interest as a possible source of petroleum.

The base of the Matanuska Formation as described by Grantz (1964, p. I-14), appears interesting from the standpoint of uranium potential. Near Wolverine Creek the formation is about 300 feet thick and is overlain unconformably by the Chickaloon Formation. The base consists of up to 30 feet of a coarse-grained pebbly sandstone composed mostly of volcanic rock fragments that were deposited in littoral and inner sublittoral marine zones. This unit grades upward into a fine-grained section containing sandy limestone concretions, fossil mollusks, wood fragments, and glauconite grains. Iron oxide has produced irregular brown staining on the outcrops. Grantz (1964, p. I-14) stated that a black sooty nickel and cobalt-bearing mineral has filled some joints in the sandstone and replaced a little of the matrix near the base.

The Paleocene and Eocene(?) Chickaloon Formation occurs throughout the lower Matanuska Valley, except where older sedimentary rocks are exposed or where younger igneous rocks have intruded. It is exposed eastward from Palmer for about 30 miles and appears to underlie about 100 square miles of the valley (fig. 16). The Chickaloon consists of at least 5,000 feet of nonmarine clastic sediments. It rests unconformably upon the Cretaceous Matanuska Formation and grades upward into the Wishbone Formation conglomerates.

Published measured sections of the Chickaloon have been concerned primarily with the coal deposits and show a monotonous sequence of shales, clays, sandstones, conglomerates, arkoses, and coal beds. A stratigraphic description can be made only in a general way because of the rapid changes in thickness of the members and questionable correlation between areas. Individual units range from a few inches up to 100 feet or more in thickness. Thin ironstone beds and nodules are frequently noted. The shales are gray, black, or drab, frequently gritty and contain nodules of iron carbonate. The sandstones are yellowish, soft, feldspathic, and poorly sorted. The formation has been intruded by numerous stocks and sills.

Coal beds are numerous in the upper 1,400 feet of the formation, especially on the north side of the valley in the Moose Creek, Eska Creek, and Chickaloon areas. Over 20 coal beds are 3 feet or more in thickness and Barnes (1967, p. B25, B27) reported that the coal beds ranged up to 23 feet at the Wishbone Hill district. One coal exposure at Anthracite Ridge laterally measured 34 feet. Plant fossils are abundant, and petrified wood occurs locally. All of the units in the formation intergrade laterally and vertically.

Freshwater limestones are scattered throughout the formation, and thick beds of conglomerate are present locally. Pebbles of the conglomerates consist mostly of quartz, chert, and fine-grained igneous and metamorphic rocks. Granitic pebbles are generally scarce, but conglomerate northwest of Wolverine Creek and on the Little Susitna River is reportedly rich in granitic pebbles. At a locality north of Wishbone Hill, sandstone and conglomerate constitute more than half the 3,500 feet of exposed Chickaloon Formation. Barnes and Payne (1956, p. 44) suggested that the Chugach Mountains were a major source of the sediments.

Wolfe and others (1966, p. A10) believe that the Chickaloon Formation is Pliocene, based on plant fossils, and that it was deposited in a subtropical or warm-temperature climate.

The Wishbone Formation, which, with the overlying Tsadaka Formation, was originally mapped as the Eska conglomerate (Martin and Katz, 1912, pl. 5). It has a maximum thickness of 3,000 feet at Castle Mountain, and about 2,000 feet of section is well exposed at Wishbone Hill. The formation is conformable with and grades into the underlying Chickaloon Formation; it is therefore dated as Paleocene(?) or Eocene(?). It is overlain unconformably by the Tsadaka Formation and volcanic rocks. The dominant color of the Wishbone Formation is a light-tawny red, but some sandstones are gray or whitish. The Wishbone consists predominantly of conglomerate, but contains numerous beds of cross-bedded feldspathic sandstones and lenticular beds of siltstone and claystone. The conglomerate consists of pebbles of fine-grained igneous and metamorphic rocks, chert, quartz, and jasper firmly cemented in a sandy matrix. Individual beds range in thickness from a few feet up to 75 feet and they are generally massive.

The sandstone beds are thin bedded, but one bed was reported to be 25 feet thick. Clasts are mostly between 1/2 and 4 inches in diameter and consist of porphyries, granites, fine-grained igneous rocks, vein quartz, and quartzites in a sandy or arkosic matrix. On Moose Creek, granite and diorite boulders up to 4 feet in diameter are present. Occasionally poorly preserved fossil sticks were found on Wishbone Hill, but no coal.

The Tsadaka Formation has been identified only on the southwest side of Wishbone Hill, where it covers less than 1 square mile. The formation lies unconformably on the Wishbone Formation beds, which are more highly deformed. Fossil evidence is not available, but the Tsadaka is assumed to be Eocene or younger (Barnes, 1962). The formation consists of a minimum of 700 feet of poorly indurated siltstone, pebble sandstone, and coarse conglomerate characterized by cobbles and boulders of coarse-grained granitic rocks.

Igneous Rocks

The Jurassic Talkeetna batholith is exposed along the north side of the Matanuska Valley. It consists of a large complex mass of granitic intrusives, mainly granodiorite and quartz diorite (Barnes, 1962).

A belt of Jurassic diorite 1 to 4 miles wide in the Chugach Mountains parallels the Matanuska Valley between 3 and 6 miles south of the Matanuska River. The diorite cuts the older Talkeetna formation greenstone of Early Jurassic age, and consists almost entirely of nearly equal amounts of soda feldspar and hornblende. Quartz is present in amounts less than 5 percent. Biotite, apatite, and pyrite are minor accessories. Alaskite dikes associated with the diorite mass also cut the greenstone.

Tertiary intrusive rocks are mostly confined to the eastern half of the lower Matanuska Valley. They form several stocklike masses ranging up to several square miles in outcrop area and include dioritic, trachytic, and basaltic rocks. A volcanic plug of rhyolite of probable Eocene age forms the core of Kings Mountain. Quartz and orthoclase are the principal minerals, and muscovite and hematite are secondary.

Interbedded lava, tuff, and breccia of basaltic composition rest unconformably on the Wishbone formation in small patches on Castle Mountain. These beds are remnants of more widespread flows. They are nearly flat lying and total about 700 feet in thickness.

Structure

The lower Matanuska Valley is in a narrow structural trough that is part of the Matanuska geosyncline, named by Payne (1955). The geosyncline was formed in earliest Middle Jurassic and persisted as a depositional area until the orogeny in Paleocene or Eocene time. A major feature is the Castle Mountain fault, which defines the northwestern border of the trough. Along the southeast border of the valley, younger rocks of the valley floor are steeply upturned against the older rocks on the Chugach Mountains. The Tertiary sediments in the valley vary in attitudes from being slightly tilted to strongly folded. Small faults are numerous and have complicated coal-mining operations.

Economic Geology

The principal mineral resource of the lower Matanuska Valley is coal. The Matanuska coal field has been divided into four districts: Little Susitna, Wishbone hill, Chickaloon, and Anthracite Ridge. All the coal is in Tertiary beds, and all the commercial beds are in the Chickaloon Formation. Rank of the coal increases from subbituminous in the Little Susitna district on the west to anthracite in the Anthracite Ridge district to the east. The original resources of the Wishbone Hill and Chickaloon districts have been estimated to be 137 million tons (Barnes, 1967, p. B11). Most mining has been by open-pit methods, but underground work has also been done. All the mines are presently inactive.

Neither lode nor placer deposits are known in the lower Matanuska Valley. However, the Willow Creek gold lode district is located immediately west of the valley area on the southwestern flank of the Talkeetna batholith, about 10 to 15 miles northwest of Palmer. The district has been Alaska's second largest gold lode producer. The geology has been described by Ray (1933). Precambrian Birch Creek schist was intruded during the Mesozoic by the Talkeetna batholith. Quartz diorite is the main constituent, but some phases range from quartz monzonite to gabbro. Gold-bearing quartz veins have intruded along joint planes and shear zones both in the Birch Creek schist and the intrusive rock. Dikes of pegmatite, aplite, lamprophyre, and diabase are common in the district. Gold, silver, copper, mercury, lead, zinc, molybdenum, nickel, and tungsten have been reported from among the district's 39 lode deposits listed by Cobb (1969).

Radioactivity Investigations

A reconnaissance for radioactive deposits along the Matanuska Valley was conducted by Moxham and Nelson (1952, p. 6). Radioactivity tests on 17 samples from stream concentrates, from a basic intrusive east of Chickaloon, and from Matanuska Formation shale produced eU values from 0.000 to 0.002 percent. Spot checks on coal, gypsum, and basic dikes gave insignificant values.

Eakins (1969, p. 18) examined coal, sandstone, shale, and conglomerate in the open-pit coal mines at Eska and Jonesville with a scintillometer. Maximum counts were not over two to three times greater than background.

A brief field examination of radioactive pegmatite dikes in the Willow Creek mining district was made by the U.S. Geological Survey (Moxham and Nelson, 1952, p. 7-11). It appeared that the radioactive minerals were sparsely disseminated throughout most of the pegmatites but concentrated in association with biotite plates up to 1 inch in diameter. Radioactive minerals identified were uraninite, thorite, cyrtolite, and allanite. Other dikes and vein materials in the district were nonradioactive.

Radiometric analyses of channel samples of the pegmatites from the Fishhook Creek—Archangel Creek area of the Willow Creek mining district are given by Moxham and Nelson (1952, p. 10):

Sample no.	Location	Unconcentrated (percent eU)	Heavy fraction (percent eU)[1]	Heavy fraction (percent U)	Concentration ratio
49AM by 36 3801	Fishhook Creek	0.005	0.535	---	1664:1
44 3809	------ do ------	.004	.368	---	279:1
46 3811	------ do ------	.007	2.93	---	901:1
48 3813	------ do ------	.003	.070	0.041	438:1
55 3820	------ do ------	.007	.146	---	222:1
56 3821	------ do ------	.005	.202	---	279:1
57 3822	------ do ------	.005	.178	.056	227:1
58 3823	------ do ------	.005	.142	.042	430:1
66 3831	Archangel Creek	.004	.024	---	236:1
67 3832	------ do ------	.002	.022	---	161:1
68 3833	------ do ------	.003	.016	---	207:1
69 3834	------ do ------	.004	.027	---	299:1
70 3835	------ do ------	.003	.142	.017	599:1
71 3836	------ do ------	.004	.120	.019	478:1
72 3837	------ do ------	.003	.065	.031	369:1

[1]eU: equivalent uranium.

All the operating gold mines in the Willow Creek district were checked underground and mine dumps were tested, but no radioactive material of interest was found (Wedow and others, 1951, p. 80).

Discussion

Arkosic and carbonaceous sandstones derived largely from granitic and volcanic rocks are common in the lower Matanuska Valley, but are restricted to a narrow trough and are moderately to highly deformed. The limited area involved suggests that the processes necessary for the formation of commercial sedimentary uranium deposits may not have operated to the extent necessary. However, the basal pebbly sandstone of the Matanuska Formation near Wolverine Creek that is iron stained and contains a black sooty nickel and cobalt-bearing mineral as joint fillings and replacements of the matrix should be reexamined.

The radioactive pegmatite dikes in Willow Creek mining district do not appear to justify additional study in view of their low equivalent uranium assays and the lack of significant radioactivity in the vein materials and stream concentrates.

Data on the radioelemental content of the intrusive rocks bordering the Matanuska Valley are lacking.

COPPER RIVER BASIN

The Copper River Basin is a topographic and structural basin in south-central Alaska. It is bounded on the north by hills along the southern flank of the Alaska Range, the Wrangell Mountains on the east, the Chugach Mountains on the south, and the Talkeetna Mountains on the west (fig. 17). Fringe areas considered include the upper end of Matanuska Valley, the Gulkana upland along the southern flank of the Alaska Range, and the Chitina River Valley, located between the Wrangell and Chugach Mountains. The Copper River Basin is roughly about 80 miles across from east to west and is mostly within the Valdez and Gulkana quadrangles of the U.S. Geological Survey topographic map series. The eastern and southern parts of the Copper River area are accessible by the Richard-

Figure 17. Index map, Copper River Basin (1 inch = 25 miles).

son, Glenn, and Edgerton highways. The Denali Highway crosses the northern end. Small landing fields are located at a number of the settlements along the highways.

The early history and development of the region are closely tied to the famous Kennecott Copper Corporation mines located in the Wrangell Mountains near McCarthy, on the north side of the Chitina Valley. Recent interest in the region has been directed towards determining the petroleum possibilities of the Mesozoic section of the Copper River Basin.

The altitude of the lowlands in the basin is between 2,000 and 3,000 feet above sea level. It is occupied by numerous lakes and is drained principally by the Copper River, which has its outlet in the Gulf of Alaska; drainage is poorly developed over a large area, and ground travel is difficult. The mountains bordering the basin are high and rugged and have been the source of many glaciers which have supplied drift coverage in the lowlands and created the innumerable small glacial lakes. Glaciers are still abundant in the Alaska, Wrangell, and Chugach ranges. Mt. Blackburn and Mt. Sanford in the Wrangells are both over 16,000 feet high. The 14,000-foot-high Mt. Wrangell volcano emits smoke and steam.

The climate is much more arid than in the coastal regions; at Copper River townsite the average annual precipitation is barely over 9 inches. The region is in the belt of discontinuous permafrost.

The geology of portions of the province has been described and mapped by Chapin (1918), Mertie (1927), Moffit (1938), Capps (1940), and Andreason and others (1964).

Sedimentary Rocks

The Copper River Basin is Cenozoic but the southern part includes a thick sequence of Mesozoic sediments of the Matanuska geosyncline (Payne, 1955). The deepest test well in the basin was drilled to 8,837 feet and was still in Jurassic sediments. Most of the units have been dated approximately by marine fossils but complicated structure, rapid changes in lithology and thicknesses, and extensive erosion make some correlations doubtful and confusing. While most of the pre-Tertiary units are clearly marine or marginal marine, there are several thick sandstone and conglomerate sections of interest exposed in the Chitina Valley area and to a lesser extent in the southwestern part of the basin in and north of the upper Matanuska Valley. The stratigraphic units are remnants of the once-extensive deposits which in part extend beneath the Quaternary cover in the Copper River basin. Some of the Mesozoic sandstones are arkosic and tuffaceous, and contain a small amount of carbonaceous material; these will be discussed in the following summary of the stratigraphy. The Tertiary beds are of continental origin and are probably the most interesting rocks in the region with respect to uranium potential, although outcrops are very limited. Generalized stratigraphic sections for the east and west sides of the basin are shown in figures 18 and 19.

Descriptions of much of the stratigraphy is necessarily based upon work in the upper part of the Chitina Valley, as much as 100 miles from the Copper River Basin lowlands, where outcrops are available for examination and where mining has been important. Grantz (1965) produced a detailed map and cross sections

Period	Epoch	Formation	Thickness
Quat.	Miocene-Pliocene	Wrangell Lava	0-5,000'
Tert.	Miocene	Frederika Fm.	2,000'
Cretaceous	Upper Cretaceous	MacCall Fm.	2,500'
		Chititu Fm.	5,500'
		Schultz Fm.	225'
		Moonshine Creek Fm.	3,500'
	Lower Cretaceous	Kennecott Fm.	1,500'
Jurassic	Upper Jurassic	Root Glacier Fm.	0-4,000'
	Middle and Upper Jurassic	Nazina Mountain Fm.	0-1,400'
		Kotsina Conglomerate	2,000-2,500'
Triassic	Lower Jurassic	Lube Creek	300'
	Upr. Triass. & Lwr. Jurassic	McCarthy Shale	1,500-3,000'
		Nizina Limestone	1,100'
	Upr. Triassic	Chitistone Limestone	1,900'
	Mid. &/or Upr. Triassic	Nikolai Greenstone	5,000'
Permian	Lower Permian	Hansen Creek Fm.	900'
		Station Creek Fm.	6,500'

Base not exposed

Figure 18. Generalized stratigraphic section--east side, Copper River Basin (Chitina Valley area), Alaska. (Source: Alaska Geological Society Stratigraphic Committee, 1969-70.)

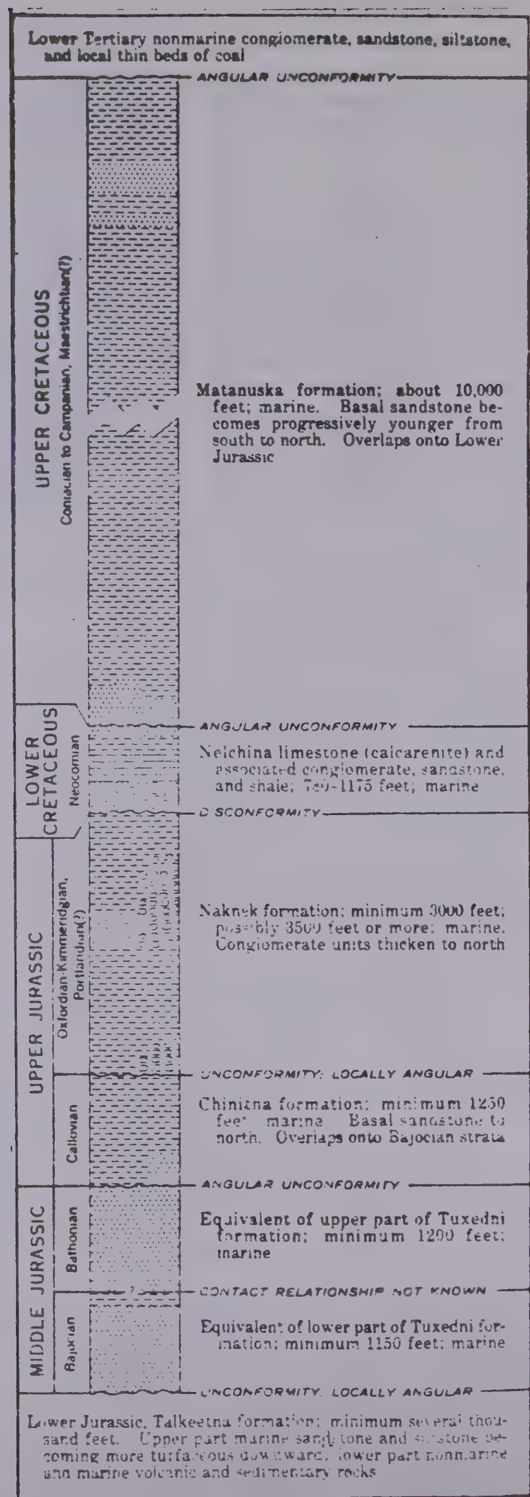


Figure 18. (cont.). Generalized stratigraphic section--west side, Copper River Basin (Nelchina area), Alaska. (Source: Grantz, 1965, U.S. Geol. Survey Bull. 1094, pl. 4.)

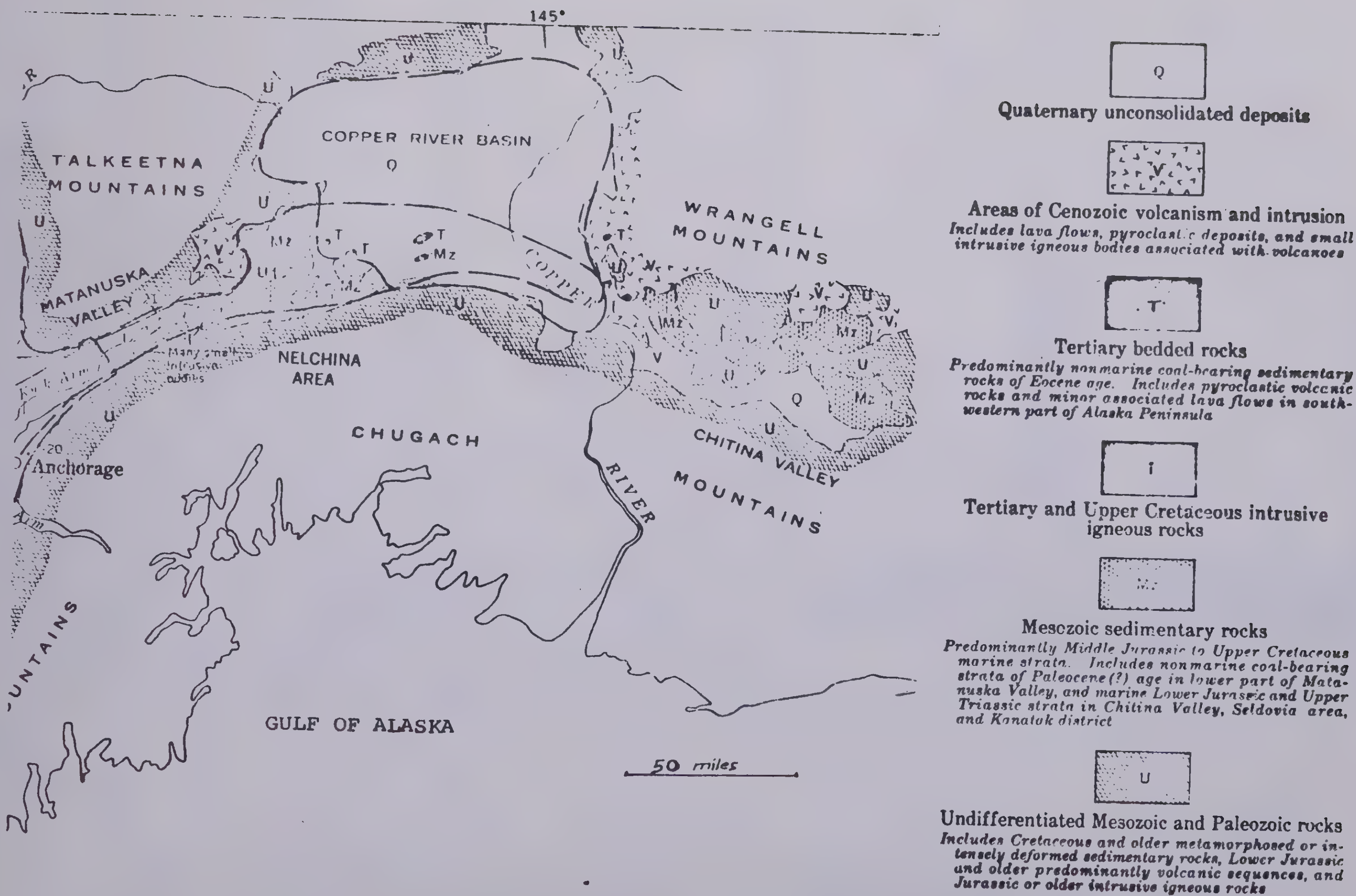


Figure 19. Geologic map of the Copper River Basin region. (Source: Miller, Payne, and Gryc, 1959, U.S. Geol. Survey Bull. 1094, pl. 4.)

of the western flank of the basin that show subdivisions of the Mesozoic units and illustrate the complex structure along the eastern side of the Talkeetna Mountains.

The oldest rocks in the Copper River Basin are Mississippian and Permian; the Pennsylvanian system is probably not represented. Miller and others (1959, p. 13) give the thickness of the Mississippian section in the Chitina Valley as at least 6,500 feet of slate and schist with minor limestone and volcanic rocks. The Permain was believed to include several thousand feet of interbedded volcanic rocks, limestones, and clastic sediments, followed by 5,000 to 6,000 feet of lava flows, at least part of Permian age. The Carboniferous rocks generally display complicated folding and faulting. Andreason and others (1964, pl. 24) divided the Carboniferous and older rocks into two units. One unit is present in a broad belt across the northern part of the basin in the foothills of the Alaska Range. The rocks in this belt are predominantly metamorphosed volcanic rocks with some sedimentary beds. The other unit is present in the northeastern and southeastern parts of the basin and in the Chitina Valley and consists mostly of metamorphosed sediments with minor amounts of volcanic rocks and unmapped felsic to mafic intrusives. The sediments include schist, slate, altered limestone, and tuffs.

Middle and upper Triassic rocks crop out in a broad belt across the southern flank of the Alaska Range, north of the Carboniferous belt, and in the Chitina Valley (Andreason and others, 1964, pl. 23). The rocks consist of 5,000 feet or more of altered basalt and andesite flows known as the Nikolai Greenstone. The Nikolai is of interest to prospectors because it is a host for copper deposits at numerous places in the Wrangell Mountains. About 5,000 feet of marine sedimentary rocks overlie the Nikolai Greenstone in the Chitina Valley where they form the most complete Triassic section in Alaska. These include the Late Triassic Chitistone Limestone which is dolomitic in part and the host for the massive copper deposits near Kennicott, where it is up to 3,000 feet thick. A 300-foot-thick formation consisting of impure spiculite and coquina overlies the McCarthy Shale in the McCarthy C-5 quadrangle (MacKevett, 1971, p. 15).

Several thousand feet of altered marine pyroclastics rocks of the Lower Jurassic Talkeetna Formation are present as lavas and tuffaceous sediments in the Talkeetna and Chugach Mountains (Grantz, 1965). Marine sedimentary rocks of Early Jurassic age occur in the upper Chitina Valley. Thus the southeastern part of the Copper River Basin may contain a Lower Jurassic rock facies transitional between the lava-bearing Talkeetna Formation and the sedimentary rocks of the upper Chitina Valley (Andreason and others, 1964, p. 138). Moffit (1938, p. 62) states that Middle and Upper Jurassic rocks are widely distributed in the Chitina Valley, but occupy only a small total area. They include several thousand feet of tuff, shale, limestone, sandstone and conglomerate. While the Jurassic sediments are considered to be of marine origin, one unit of tuffaceous conglomerate may be of interest with respect to possible uranium content. This unit, the Kotsina conglomerate (Moffit, 1938, p. 62-64), unconformably overlies the Nikolai Greenstone and Triassic shale and limestone on the east side of the Copper River and north of the Chitina River between the Kotsina and Cheshnina Valleys. The age is now accepted as Jurassic (Levorsen, 1973). The unit is at least 1,500 feet thick, and consists of pebbles or argillite, diorite, greenstone, and quartz in a tuffaceous matrix. Several small areas of unaltered brownish-gray sandstone southeast of Chitina townsite may be equivalent to the tuffaceous beds. The sandstone contains much quartz, unaltered feldspar, and biotite in a calcareous cement and some black spots thought to be organic remains. It contains a few very thin beds of

black shales. It may be significant that the tuffaceous beds appear to overlie the conglomerate and thereby provide a possible source and host for uranium. The original extent of these beds is not known, but the geologic map by Moffit (1938, pl. 2) indicates the Kotsina conglomerate underlies about 50 square miles and forms steep cliffs in the mountains.

The Middle Jurassic is represented in the southwestern part of the Copper River Basin area by the Tuxedni Formation which overlies the Talkeetna Formation (Chapin, 1918, pl. II; Grantz, 1960, 1965). The Tuxedni is not described in detail in this area, but it is considered to be entirely marine and to consist of buff sandstone, soft sandy shale, and a smaller amount of dark-brown arkosic sandstone containing "black minerals" (Chapin, 1918, p. 32). The type section of the Tuxedni Formation is in the Tuxedni Bay in the Cook Inlet, where it is at least 1,500 feet thick. It may reach 1,000 feet in thickness in the Matanuska Valley. Regardless of its marine origin, the arkosic and tuffaceous nature of the sandstone and fossil vegetable remains (Martin, 1926, p. 224) may provide a suitable environment for uranium in this area. The Tuxedni Formation in the upper Matanuska Valley region is overlain by a thick Middle Jurassic shale sequence with minor sandstones named the Chinitna Formation, and Upper Jurassic shales, sandstones, and limestones of the Naknek Formation.

Cretaceous marine sediments occupy a large part of the upper Chitina Valley. The beds include black shale, sandstone, conglomerate, grit, and sandy shale, but no limestone. Large masses of granite and quartz diorite cut the beds. A distinct unconformity separates the Cretaceous from the older sediments and it is notably less folded and faulted. The Cretaceous sediments in the Chitina Valley and adjacent area have been described by Moffit (1938, p. 78) as forming a sequence with a total thickness of at least 6,000 feet, but nowhere is there a complete Cretaceous section. The sequence was divided into three general groups: a basal sandy unit from 300 to over 500 feet thick; a middle black-shale unit containing beds of red shale, limestone, sandstone, and conglomerate totaling not less than 3,000 feet; and an upper unit of possibly 3,000 feet of conglomerate, sandstone, and sandy shale.

More recently, Jones and MacKevett (1969) divided the Cretaceous rocks in the McCarthy quadrangle, north of the Chitina Valley, into five formations: the Kennicott, Moonshine, Schulze, Chititu, and McColl Ridge. The Kennicott Formation was redefined to include only rocks of Lower Cretaceous age. The basal part of the Kennicott Formation was described as poorly bedded wackes and arenites. The dominant clasts of the feldspathic wackes are quartz and plagioclase, chiefly labradorite or calcic andesine. Less abundant are K-feldspar, lithic fragments, calcite, chlorite, glauconite, and opaque minerals, mainly leucoxene, hematite, ilmentite, and magnetite. Carbonaceous debris was noted in the matrix. A microcrystalline matrix making up from 10 to 35 percent of the rock suggests a lack of porosity.

Overlying the Kennicott Formation, the Upper Cretaceous Moonshine Creek, Schulze, Chititu, and McColl Ridge Formations comprise several thousand feet of sandstone, conglomerate, siltstone, and shale. The Moonshine Formation is dominantly siltstone and sandstone, 3,500 feet thick, described as chiefly feldspathic wacke with clasts mostly of quartz and plagioclase. The Schulze Formation consists of 100-225 feet of siliceous pelitic rock called "porcellanite." It contains minor hematite and carbonaceous debris. The Chititu Formation has an apparent thickness of 5,500 feet and consists mostly of mud-

stone and shale. The McColl Ridge Formation overlies the Chititu Formation with apparent conformity and is dominantly a light-gray coarse-grained sandstone. It includes some siltstones that also contain carbonaceous debris.

The thickest section of Cretaceous sandstone described is located on the ridge at the head of Young Creek in the upper portion of the Chitina Valley. About 2,500 feet of nearly horizontal beds of sandstone, arkose, shale, and conglomerate cap the ridge and occupy an area about 15 miles long and 3 miles in maximum width (Moffit, 1938, p. 73). Although the beds are considered to be of marine origin, their arkosic content and the presence of a certain amount of plant remains along with the excellent exposures of the section may justify their examination for possible uranium content. A generalized description of the conglomerate is given by Moffit (1938, p. 74):

Section of Cretaceous conglomerate, arkose, and shale on Young Creek

	Feet
Sandstone, coarse, green and gray, interbedded with dark shale containing imperfect plant remains	*700*
Shale, brown and gray, with subordinate dark beds	*700*
Sandstone, greenish or greenish gray	*100*
Shale, fine-grained, brown, gray, or greenish gray	*700*
Conglomerate and sandstone	*300*
	2,500

In the southwestern part of the Copper River Basin, the Cretaceous is divided into the Nelchina limestone and associated beds of late Early Cretaceous age and the Matanuska Formation, assigned to the Late Cretaceous.

Whereas the Upper Cretaceous sandstones are feldspathic and contain some minor amounts of carbonaceous debris in the pelitic units, the abundance of marine fossils and carbonate cement indicate that the sequence is probably more nearly totally marine and less favorable for uranium deposits than the underlying Kennicott Formation.

Following a general uplift at the close of the Cretaceous or at the beginning of Tertiary time, a wide, low depression was developed in the Copper River region. Tertiary continental sediments, which included sandstone, conglomerate, siltstone, claystone, and locally, beds of coal, were deposited over this area. The rocks are considered to be Eocene on the basis of poorly preserved plant remains (Moffit, 1938, p. 97). Lava flows and pyroclastic deposits of Tertiary to Recent age are extensive around the volcanic centers in the Wrangell Mountains.

Because glacial and alluvial deposits of Quaternary age now mask the older sediments in the basin by thicknesses of 600 feet or more in places and possibly as much as 1,000 feet (Andreason and others, 1964, p. 138), the thickness and distribution of the Tertiary are not well known. A limited amount of information is provided by seven electric logs from petroleum test wells, but detailed descriptions of the lithologies do not seem to be available. Locations of wells and stratigraphic sections are shown in figure 20. Two stratigraphic sections constructed from the logs are shown in figures 21 and 22. The sections show

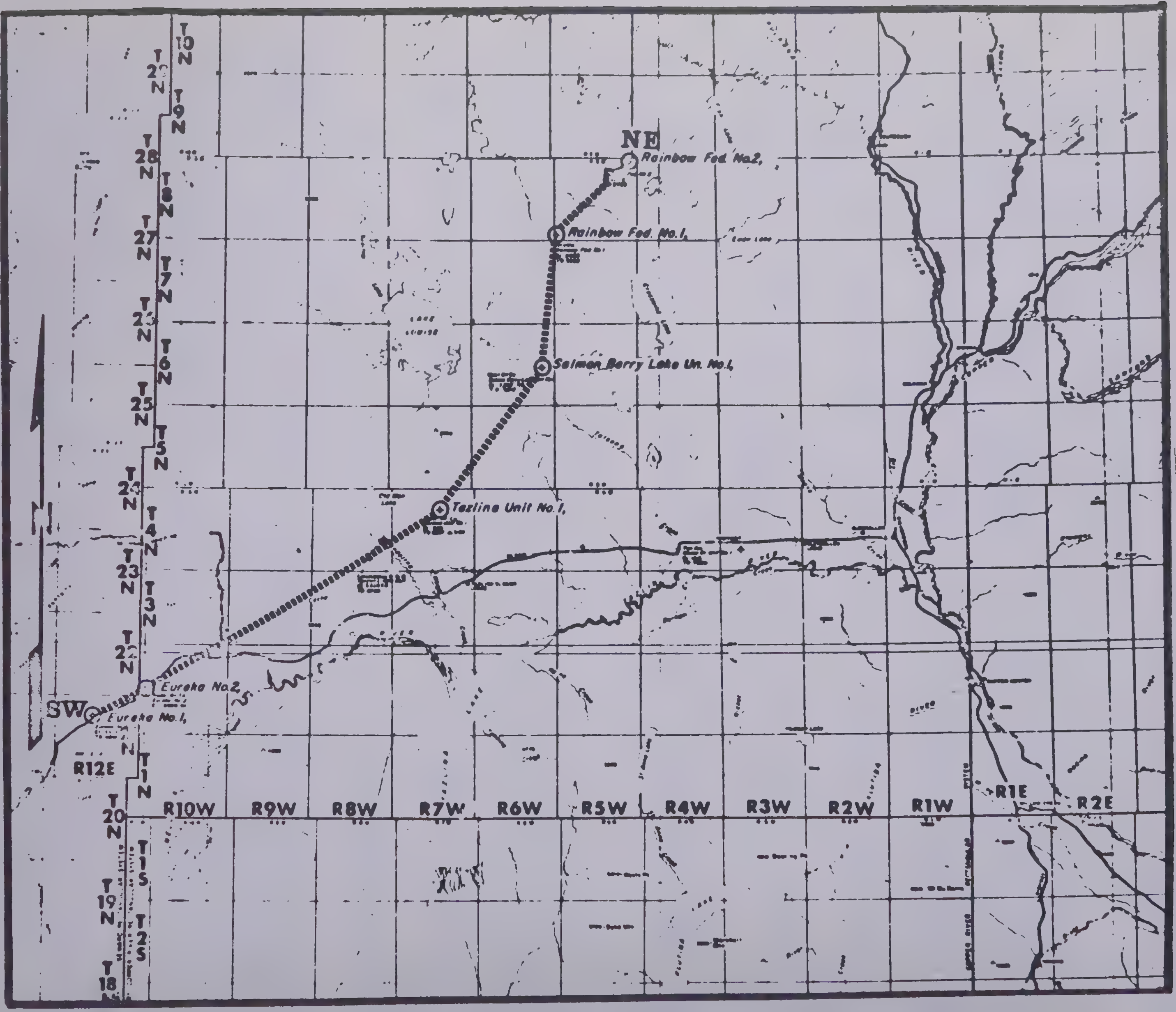


Figure 20. Location of wells and stratigraphic sections in Copper River Basin. (Source: Alaska Geological Society, 1969-70.)

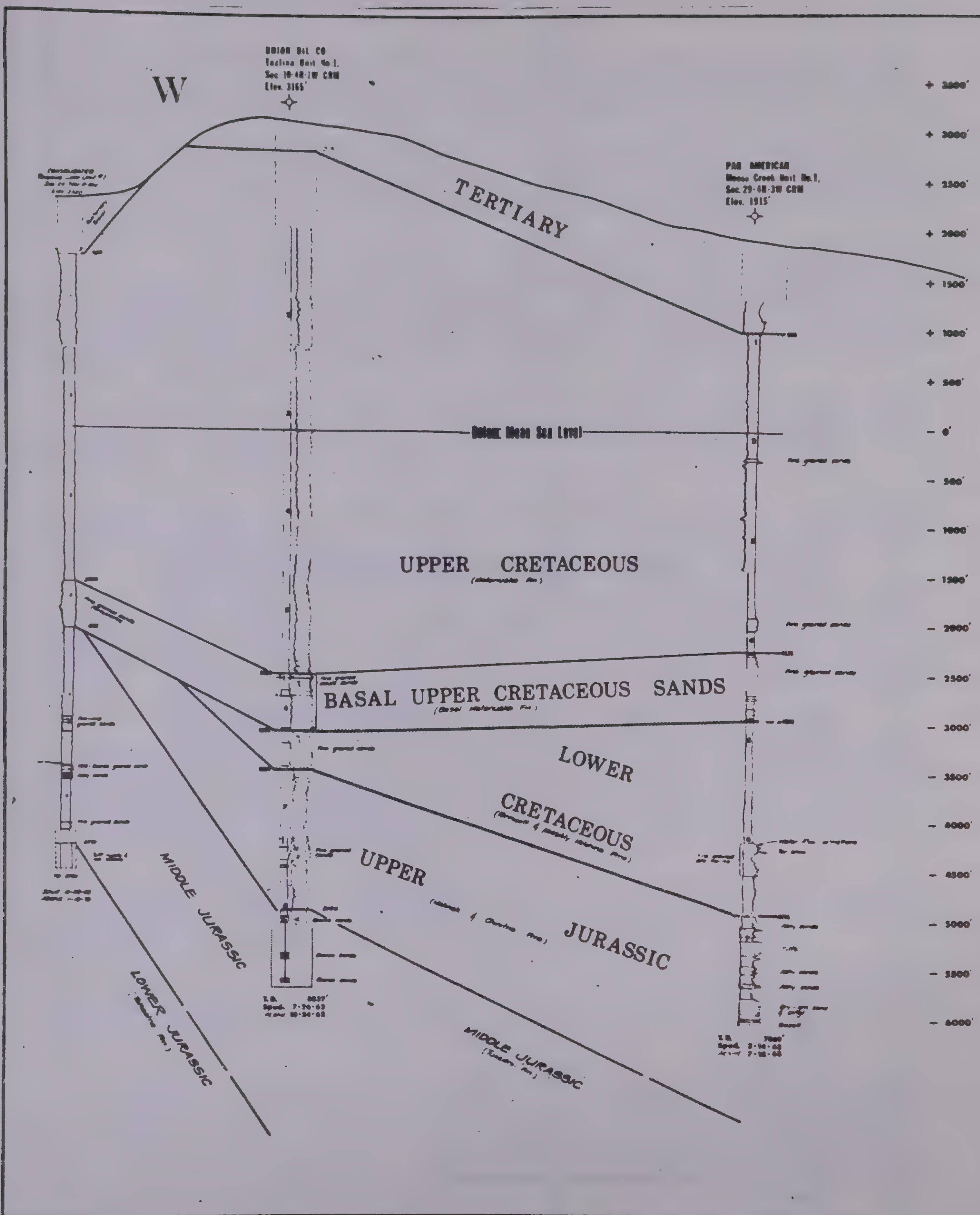


Figure 21. Stratigraphic correlation section, Copper River Basin, Alaska. Horizontal scale - none. (Source: Alaska Geological Society Stratigraphic Committee, (1969-70.)

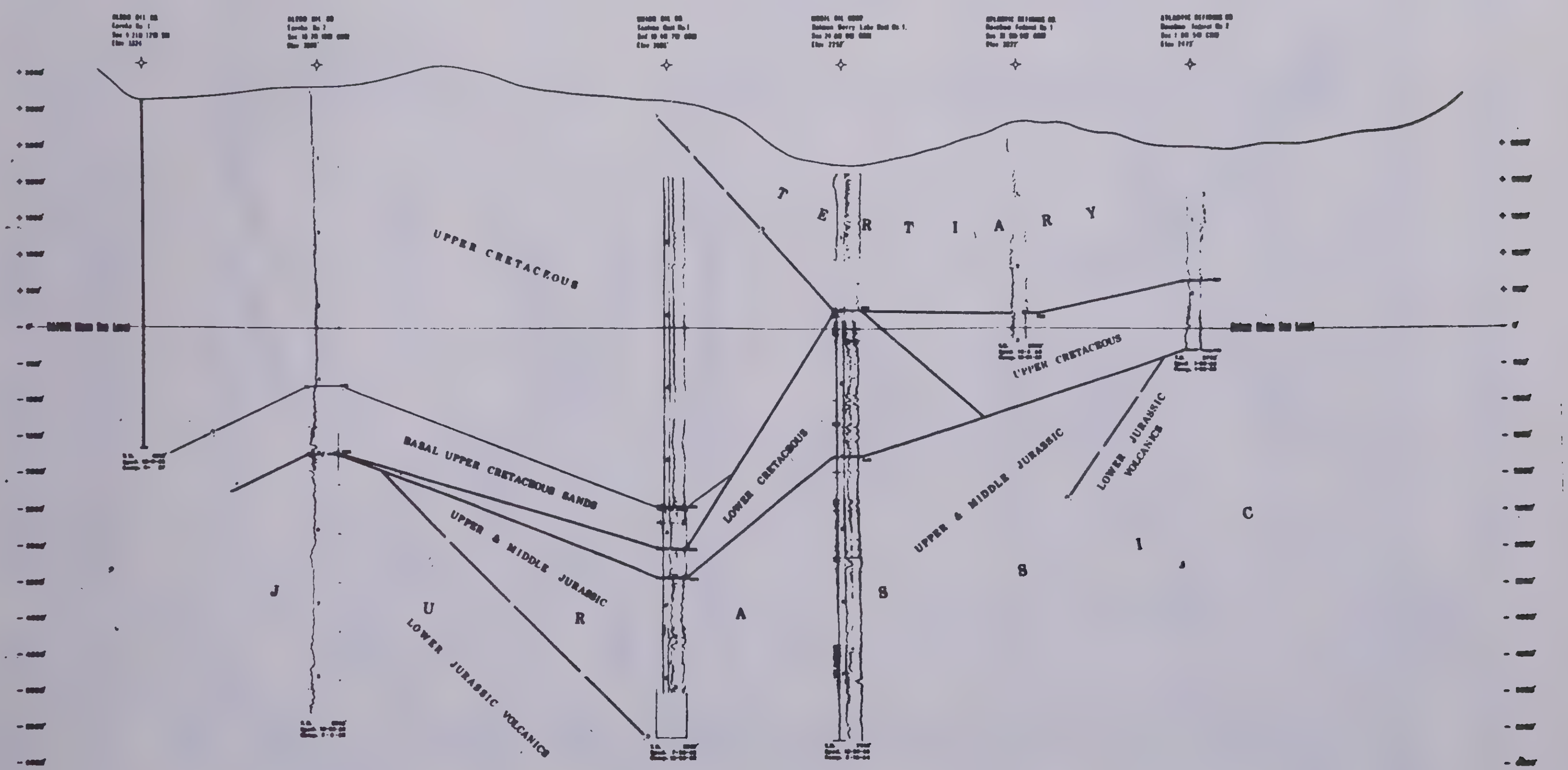


Figure 22. Stratigraphic correlation section, Copper River Basin, Alaska. Horizontal scale - none. (Source: Alaska Geological Society Stratigraphic Committee, 1969-70.)

the combined thickness of the Quaternary and Tertiary sediments ranges from 0 to 2,630 feet, as shown by the top of the Cretaceous. The thickest section was penetrated by Atlantic's Rainbow 1, 30 miles northwest of Gulkana Junction.

Sample logs on the Copper River Basin wells on file at the Alaska State Division of Oil and Gas in Anchorage were examined by the writer. Sample quality was generally poor, but the following comments indicate the general nature of the sediments penetrated.

A sample log on Pan American's Moose Creek Unit 1 gave a general description of the sediments between 600 and 7,860 feet. Shale, sandy and silty shale, and quartz and glauconitic sandstones are the principal lithologies. The presence of bentonite, pyrite, and smoky quartz were noted at several intervals between 1,800 and 7,860 feet.

The Aledo Oil Company Eureka 2 sample log describes samples between 4,100 and 8,540 feet. The sediments penetrated were principally varicolored conglomerate and siltstone.

Union Oil Company's Tazlina 1 penetrated poorly sorted rusty sandstone and conglomerate between depths of 100 and 300 feet. From 300 feet to the bottom of the hole, shale and siltstone with some tuffs and pyrite predominated.

Samples from Consolidated, Allied, and Embassy Miami Tawawe Lake Unit 1 were logged between depths of 450 and 6,850 feet. These consisted largely of quartz sandstone, siltstone with minor tuffs, and carbonaceous material to 5,850 feet. Between 5,850 and 6,850 feet, volcanic breccia and tuff composed almost 100 percent of the material.

Samples described from Mobil's Salmon Berry Lake Unit 1 were reported as interbedded sandstone, claystone, and siltstone with some coal above 4,250 feet. Below 4,250 feet claystone, tuffs, tuffaceous sandstone, and volcanic debris were most abundant. A gamma-gamma log showed two thin zones at 3,070 and 3,210 feet with several streaks with four times the background.

Eleven sidewall cores from Atlantic Richfield's Rainbow Federal No. 2 taken at intervals between 1,184 and 2,328 feet were all described as sandstone and conglomerate, much of which was "ashy" or bentonitic.

Atlantic Richfield's Rainbow Federal No. 1 well cuttings, logged from 220 to 2,800 feet, consisted of sandstone, in part varicolored, conglomerate, claystone, or coal.

Andreason and others (1964, pl. 24) show a section from a 930-foot water well drilled 4 miles north of the Tazlina Glacier Lodge on the Glenn Highway. This apparently is near the part of the basin where the total Mesozoic and Cenozoic sediments are thickest. The section shows 105 feet of alluvium and glacial deposits, 102 feet of Tertiary continental sediments, and 720 feet of Jurassic and Cretaceous marine sediments.

Tertiary sediments can be seen in outcrop in two general areas in the Copper River basin region: in the northeastern part between the Chistochina River and the Richardson Highway; and in the southwestern part north of the Glenn Highway and on the western side of the Talkeetna Mountains.

Eocene sediments in the northeast part consist of more than 2,000 feet of section, which has been named the Gakona Formation (Mendenhall, 1905, p. 52-53). The largest outcrop lies adjacent to the eastern side of Gakona Glacier and covers 20 to 25 square miles. A basal conglomerate here is not less than 500 feet thick and is made up of coarse, indurated igneous rocks that dip eastward and appear to pass beneath soft, fissile or massive, gray or buff-colored shales which, with interbedded gravel, sand, and lignite beds, extend to the head of the west fork of the Chistochina River.

Tertiary beds of conglomerate, clays, and coals of variable thicknesses and erratic distribution occur in the Wrangell Mountains and the Chitina Valley area: these appear to have been deposited in local depressions on the old land surface (Smith, 1939, p. 60). While these small patches of Tertiary sediments in the Wrangells and the Chitina Valley are presumed by the writer to be too limited for uranium accumulations, the following section measured by Moffit (1938, p. 94) near the lower end of Frederika Glacier is given as an example:

Section in gulches near lower end of Frederika Glacier

	Feet
Basalt, great thickness.	
Light-yellow tuffaceous bed	*12-15*
Gray sandy shale splitting into thin sheets	*5*
Black shale	*15*
Black sandy shale splitting into thin sheets	*5*
Coarse gritty tuff or sandstone, thin sandstone beds, variegated fine clay, black shale, and thin coal beds; abundant fossil leaves	*150*
Gray, yellowish-weathering conglomerate, finer above, containing local beds of shale	*100*
Brown-weathering conglomerate with well-rounded pebbles 2 inches or less in diameter	*20*
Basalt (Permian?).	*320*

Several hundred feet of Tertiary sediments are present in small scattered exposures in the southwestern part of the basin north of the Glenn Highway, but a complete section has not been found. Volcanic beds and conglomerates are present for about 12 miles along the eastern side of the Talkeetna Mountains, north of the Little Nelchina River (Chapin, 1918, pl. II). The outcrop is up to 4 miles wide. The conglomerate is nearly horizontal and underlies basaltic flows. The unit has been described Paige and Knopf (1907, p. 21):

> *Occasional thin layers of sandstone show that the conglomerate is lying in horizontal attitude. It is almost exclusively composed of large well-rounded boulders of augite andesite and quartz monzonite embedded in a tuffaceous matrix. In the upper horizons the boulders of andesite preponderate. The boulders of the conglomerate are ellipsoidal in shape, and many of them are as much as 2 feet in diameter. The conglomerate is lithified firmly enough to form large boulders in the present stream wash. Sheets of lava are occasionally intercalated in the conglomerate.*

Paige and Knopf assigned the unit to the Jurassic but later work by Moffit indicated a Tertiary age.

Igneous Rocks

A wide variety of intrusive and extrusive rocks are extensively present in the hills and mountains surrounding the Copper River Basin. These were emplaced during numerous periods of activity. Flow rocks are exposed over large areas, but intrusive rocks, while widely distributed, crop out in relatively few places.

Volcanic flows are present as a major part of the Carboniferous and older sequences extending across the northern margin of the Copper River Basin in the foothills of the Alaska Range. Lavas are also constituents of the Carboniferous sequences in the Chitina Valley (see Andreason, 1964, pl. 24; and Chapin, 1918, pl. II). A 4,000-foot sequence of basaltic lavas are present in the Wrangell Mountains as a part of the Permian Station Creek Formation (Smith and MacKevett, 1970, p. Q6).

The Talkeetna Mountains include a large core of quartz diorite and granite to the west of the Copper River Basin. The intrusives range in age from Carboniferous to Cretaceous. Tuffs and flows, in general andesitic but ranging in composition from rhyolite to basalt, are also present in the Talkeetna and Chugach Mountains as the lower part of the Talkeetna Formation. In this general area numerous small light-colored granitic and porphyritic intrusives are scattered between the Copper River and Klutina River.

Younger intrusives, Upper Jurassic to post-Eocene, occur in the Chitina Valley and adjacent areas. These include granodiorite, quartz latite, quartz diorite, granite, and syenite (Moffit, 1938, p. 106-107).

The Triassic Nikolai Greenstone overlies the Lower Permian lavas and sediments and occupies numerous areas in the Wrangell Mountains and along on the north side of the Chitina Valley for 100 miles. It is a thick sequence of basaltic flows, well known because of the associated copper deposits in the Kennicott mines near McCarthy. The primary minerals in the lava, in order of abundance, are augite, labradorite, iron ores, apatite, olivine, and orthorhombic pryoxine (Moffit, 1938, p. 39). The lavas that actually make up the bulk of the Wrangell Mountains are those of the Wrangell Lava Formation of Eocene and Quaternary age. Andesite is the chief rock type, but some basalt and dacite are present. Basaltic lavas and minor felsic extrusives and pyroclastics, containing Eocene plants, possibly equivalent to the Wrangell lava, are widespread in the southern Talkeetna Mountains.

The literature on the igneous rocks of the Copper River Basin region indicates that basic compositions, especially basaltic and andesitic, may predominate. However, intermediate to acidic intrusives are present in a large part of the Talkeetna Mountains, with small amounts in the southern part of the basin west of the Copper River and in the Chitina Valley. Many types of both sedimentary and igneous rocks were probably being eroded during deposition of the Eocene nonmarine sediments in the Copper River Basin, and it appears that intermediate to acidic types could have contributed significant amounts.

Structure

The lower Jurassic Seldovia and Talkeetna geanticlines trend through the northern part of the Chugach Mountains and the northern half of the Copper River Basin, respectively (Payne, 1955). Between the geanticlines lie sedimentary rocks

deposited in the Matanuska geosyncline during the Mesozoic era. These sediments trend into the Matanuska Valley to the west and into the Chitina Valley to the southeast. The Mesozoic sediments form a sequence having a thickness of at least 8,900 feet where the axis of the narrow Matanuska geosyncline crosses the southern part of the Copper River Basin.

The Castle Mountain thrust fault which is a major feature on the north side of the Matanuska Valley probably extends eastward into the Copper River Basin as a set of northeast-trending branch faults. Folding of the bedded rocks in the region is pronounced in the Carboniferous rocks but becomes progressively less so in the younger strata. Mesozoic beds on the western edge of the basin next to the Talkeetna Mountains are generally flat lying, except where faulted (Grantz, 1960). The Tertiary sediments are apparently nearly horizontal wherever found in the basin.

Economic Geology

It is estimated that about 3,500 square miles of the Copper River Basin is underlain by Late Mesozoic marine rocks that correlate with the sequence containing indications of petroleum in the Cook Inlet. Sandstones of Middle Jurassic to Late Cretaceous age are believed to offer the best possibilities for petroleum in the Copper River Basin (U.S. Geological Survey, 1964, p. 53). Evidence of petroleum consists of a fetid odor in a few of the Cretaceous beds, gas shows in test wells, and several gas seepages at the surface. As of 1969, eight unsuccessful wells had been drilled to depths ranging from 2,793 to 8,837 feet.

The Tertiary sediments are not considered likely to be petroleum reservoirs, but they may thicken locally and contain some oil of Mesozoic origin and methane gas. This possibility is of interest because petroleum hydrocarbons are believed to sometimes provide a reducing environment for uranium deposits (Taucher, 1971, p. 5).

Numerous publications include descriptions of the many ore deposits in the region, which if the McCarthy area is included, is one of the richest mineralized parts of Alaska. Gold and copper have been most developed. Excerpts from Berg and Cobb (1967, p. 37-65) are given in an effort to summarize the information on the geology and show the variety of minerals in the three recognized mining districts within the study area.

Chistochina District

> *The Mesozoic rocks are economically important in the Chistochina district because they include the Nikolai Greenstone and overlying Chitistone Limestone, which, in the Kotsina-Kuskulana area, are host to numerous copper lodes.*
>
> *Copper, gold, silver, and molybdenum lodes in the Chistochina district were prospected from about 1898 to 1940; the greatest exploration activity was prior to 1930. Iron, lead, zinc, and bismuth also occur in some of the lodes, but no attempt has been made to exploit these metals. Most of the prospects are between the Chitina River and the crest of the Wrangell Mountains in an area drained by the Kotsina*

and Kuskulana Rivers. A typical copper deposit in the Nikolai Greenstone in the Copper Creek area is in sheared or brecciated greenstone and consists of small irregular veinlets of quartz, calcite, and epidote, and subordinate bornite, chalcopyrite, chalcocite, enargite, malachite, azurite, pyrite, and limonite. It commonly is within a few hundred feet of the top of the greenstone.

The most thoroughly explored copper deposit on Copper Creek is the Mullen prospect where the lode consists of veins of calcite, pyrite, bornite, chalcopyrite, covellite, limonite, malachite, and azurite in brecciated limestone. Samples of the two principal veins assayed 1.55-5.82 percent copper, a trace of gold, and as much as 0.28 ounces of silver per ton. Total indicated resources of the two veins is about 1,360 tons.

Other minerals reportedly present in the Chistochina district include tetrahedrite and bismuthinite on the Kluvesna River; sphalerite and galena with copper and iron minerals have been explored in the Slana area in the northeastern part of the Copper River Basin; molybdenum, mainly in a pegmatite dike, was explored on Rock Creek, also in the Slana area.

Nelchina District

The Nelchina district is the area drained by east-flowing tributaries of the Copper River from Gulkana on the north to, but excluding the Tasnuna River on the south.

Lodes in the Nelchina district have been prospected for gold, silver, manganese, and chromite. The gold lodes, which also contain a little copper, lead, and zinc, are mainly in an area southeast of Tonsina Lake, the site of considerable exploration early in the present century. On Dust Mountain, at the northeastern end of the intrusive, a body of massive chromite as much as 10 feet thick is exposed for a distance of 75 feet. Samples of the richest material assay 36.0-57.7 percent chromite, with a chrome-iron ratio of 1.20-3.06. Assays also show traces of nickel and platinum.

Nizina District

The district is dominated in the south by the Chugach Mountains, in the northeast by the St. Elias Mountains, and in the northwest by the Wrangell Mountains. Within these regions of high relief and large fields of perennial ice and snow, the only large lowland area is the valley of the Chitina River.

Lodes containing copper, silver, gold, lead, zinc, molybdenum, and nickel occur in the Nizina district, but only the lodes bearing copper and precious metals have been the sources of substantial amounts of ore. The period of greatest lode prospecting and mine development was from 1900 to 1938, when more than a billion pounds of copper was recovered, nearly all from the Kennicott mines. The group of properties known as the Kennicott mines includes the Bonanza, Jumbo, Erie, and Mother Lode mines, located at altitudes of 4,000-6,000 feet in the mountains about 7 miles north and north-northeast of McCarthy. The underground workings in the four mines were interconnected and totaled about 70 miles in length, the deepest workings reaching an altitude of about 2,800 feet. The mines exploited several ore bodies, the most important of which

were the famous Bonanza and Jumbo veins--veins that were unique in that they constituted the largest masses of almost pure copper ore that have ever been discovered. The Kennicott mines were in almost continuous operation from 1911 to 1938, during which time they yielded most of the copper produced from Alaska. The Kennicott ore bodies were in Chitistone Limestone a little above the contact with the Nikolai Greenstone. The ore occurred as veins, irregular massive replacements, and stockworks, mostly in partly dolomitic beds in the lowest 300 feet of the Chitistone Limestone.

About three-fourths of the ore mined at Kennicott consisted of sulfide minerals, of which an estimated 95 percent was chalcocite. The remaining sulfides were chiefly covellite and sparse to trace amounts of enargite, bornite, chalcopyrite, luzonite, tennantite, pyrite, sphalerite, and galena. Besides the important copper deposits, other lodes in the Nizina district have been explored for gold, silver, lead, molybdenum, antimony, and nickel.

Radioactivity Investigations

The U.S. Geological Survey examined the southwestern part of the Wrangell Mountains on the north side of the upper Chitina Valley near McCarthy (Moxham and Nelson, 1952, p. 1-3). Apparently little or no data on the mines and ores in the district are available and radioactivity data on the mineral deposits are needed. Results of tests on nine samples collected in the McCarthy area by Moxham and Nelson are given below:

Sample	Location	Type of material	Radioactivity (in percent eU)
10	Dan Creek	Shale (Kennicott formation)	0.002
11	Dan Creek tributary	Panned concentrate	.000
12	Rex Creek	Shale (Kennicott formation)	.002
13	Young Creek	Panned concentrate	.001
14	North of McCarthy	Shale (McCarthy formation)	.000
15	North of McCarthy	Greenstone (Nikolai formation)	.002
16	Near Kennicott	Granite	.001
25	O'Neill Mine, Dan Creek	Sluice-box concentrate	.000
86	Chititu Mines, Inc. Rex Creek	-----------do----------	.000
Spot checks	(1)	Shale (Kennicott formation)	Insignificant

(1) Several localities.

A single sample of the heavy mineral fraction of gravel from Golconda Creek, a tributary to Chikina and Chitina Rivers, produced eU of 0.004 percent.

The area in the Chugach Mountains including the west tributaries to the Copper River between the Tiekel and Gulkana Rivers has been called the Klutina

district. Radioactivity measurements of rocks and stream concentrates from the area are taken from Moxham and Nelson (1952, p. 4):

Sample	*Location*	*Type of material*	*Radioactivity (in percent eU)*
1	*North of Rock Creek*	*Extrusives (Carboniferous)*	*0.001*
2	*Pippin Lake*	*Diorite*	*.000*
4	*Mount du Relle*	*---------do----------*	*.001*
5	*Squirrel Creek*	*Panned concentrate*	*.000*
6	*Bernard Creek*	*Diorite*	*.000*
7	*-----do-----*	*Panned concentrate*	*.000*
8	*Rock Creek*	*---------do----------*	*.000*
9	*Little Tonsina River tributary*	*---------do----------*	*.001*
17	*Tiekel River*	*---------do----------*	*.003*
18	*Abandoned placer mine, Fall Creek*	*---------do----------*	*.003*
19	*Tiekel River tributary*	*---------do----------*	*.002*
20	*Abandoned placer mine, Boulder Creek*	*---------do----------*	*.002*
21	*Stuart Creek*	*---------do----------*	*.002*
22	*Mile 38, Richardson Highway*	*Schist*	*.002*
23	*Mile 64, Richardson Highway*	*Graywacke*	*.000*
32	*Little Tonsina River tributary*	*Panned concentrate*	*.001*
33	*Bernard Creek*	*---------do----------*	*.000*
34	*Tonsina River*	*---------do----------*	*.001*
35	*Tonsina River*	*---------do----------*	*.000*
36	*Copper River tributary*	*Panned concentrate*	*.000*
38	*Tazlina River tributary*	*---------do----------*	*.000*
39	*Little Nelchina River*	*---------do----------*	*.000*
56	*Crooked Creek tributary*	*---------do----------*	*.000*
57	*Crooked Creek tributary*	*---------do----------*	*.000*
58	*Albert Creek*	*---------do----------*	*.000*
59	*Crooked Creek*	*---------do----------*	*.000*
87	*McMahon mine, Albert Creek*	*Sluice concentrate*	*.000*
Spot check	*Along Richardson Highway*	*Graywacke and argillite (Mesozoic)*	*Insignificant*
Spot check	*Holland-Townsend prospect, 11 miles south of Tiekel*	*Gold lode, dump material*	*Do*

Several localities in the extreme northeastern part of the Copper River Basin, in the Chistochina district, were tested:

Locality	*Type of deposit*	*Radioactivity*	*References*
Rock Creek area	*Molybdenite-bearing permatite*	*0.004 percent eU or less*	*Wedow and others, 1953, p. 6, 7;*

Locality	*Type of deposit*	*Radioactivity*	*References*
			Nelson and others, 1954
Mineral Point area	*Altered shear zone containing copper, gold, silver, and traces of nickel(?)*	*0.001 percent eU*	*Wedow and others, 1953, p. 6, 8; Nelson and others, 1954*
Glenn Highway between Slana and Mineral Lake	*Tests of concentrates from gravels of streams crossing highway*	*0.003 percent eU or less*	*Wedow, Killeen, and others, 1954, p. 16-18*
Silver Creek area	*Quartz veins, containing silver-bearing galena and tetrahedrite with some gold cutting diorite*	*Veins contain 0.001 percent eU; diorite contains as much as 0.005 percent eU*	*Wedow, Killeen, and others, 1954, p. 16-18; Wedow and others 1953, p. 6, 8; Nelson and others, 1954*
Indian group	*Quartz veins containing silver-bearing galena and tetrahedrite, chalcopyrite, malachite, and azurite*	*0.004 percent eU*	*Wedow and others, 1953, p. 6, 7; Nelson and others, 1954*

An anomalous radioactivity reading was reported from an airborne survey. R.G. Bates recorded on Trace Elements Preliminary Reconnaissance report A-1726, December 3, 1953, a scintillometer reading of 1.0 mr/hr in the canyon of the Chitistone River. The background was 0.15 mr/hr. No ground investigation was made. Although only a single reading was reported, it seems to be significantly high and to warrant follow-up testing. The mouth of the Chitistone River Valley is 10 miles east of McCarthy.

Discussion

The factors that may contribute to uranium concentration in the Copper River Basin region are summarized first. There are a number of sandstones and conglomerates of Mesozoic age that are tuffaceous and arkosic, and contain some plant material. These beds occur in the Middle Jurassic Tuxedni Formation in the southwestern part of the basin; in the Upper Jurassic Kotsina Conglomerate in the Chitina Valley area and near the southwestern end of the Wrangell Mountains; and in sandstones of Cretaceous age in the Upper Chitina Valley area. Well logs indicate these units lie at considerable depth in the central part of the basin, but outcrops are generally accessible for examination in the marginal areas. Low dips of the strata and several unconformities in the section may add to the possibility of uranium concentrations.

Tertiary sediments of nonmarine origin are present in outcrops and in the subsurface in the northeastern and southwestern portions of the basin. They are possibly as much as 2,000 feet thick and flat lying. Detailed descriptions of the sediments have not been published but they may offer the most promising host for uranium deposits in the region.

Natural gas encountered in the petroleum test wells in the Copper River Basin is a possible source of reductant for uranium in overlying strata. Faulting in the basin could conceivably create a favorable situation for uranium concentration by blocking the downward migration of fluids, forming a trap on the updip side, and by possibly allowing gas to seep into the Tertiary strata from deeper zones.

The radioactive anomaly detected from the air in the Chitistone Valley strongly indicates that outcrop tests in the area are warranted. The presence of many mineral deposits, especially those containing copper, silver, lead, and bismuth, offer localities to explore for vein-type uranium deposits. Uranium might more likely be present in zones around base-metal districts rather than near their centers.

Criteria that detract from the region as a possible uranium province are: the alkaline intrusive rocks are not abundant; pyrite and oxidized zones have not been mentioned as being present in the sediments; porosities may be low; and no anomalous radioactivity has been reported from outcrops (but ground investigations appear to have been very limited). However, a review of the literature indicates that both the sedimentary rocks and the ore districts in the Copper River Basin region warrant considerable study and testing to determine their uranium potential.

YUKON FLATS DISTRICT

The Yukon Flats district (fig. 23) is a broad Cenozoic basin in east-central Alaska extending from abandoned Fort Hamlin on the Yukon River at the west end to the junction of the Salmon Fork and the Black River at the east end, a distance of approximately 200 miles (fig. 24). The basin is 40 miles wide at the western end and 85 miles at the eastern end. The Yukon Flats district is tectonically equivalent to the intermontane plateaus that exist between the Pacific Mountain and the Rocky Mountain systems of the western contiguous United States (Gates, 1963, p. 266). The district is bounded on the north by the Brooks Range, where one peak reaches a height of 9,239 feet. The Hodzana Highland and Ray Mountains to the west, the Yukon Tanana Plateau to the south, and the Porcupine Plateau to the east form the other boundaries. These boundaries have peaks with elevations ranging between 3,000 and 5,000 feet.

The topography of the Yukon Flats district consists of three levels: flats, uplands, and highlands. Nine thousand square miles of the central part of the Yukon Flats district consists of marshy lake-dotted flats rising from 300 feet in altitude on the west to 600-900 feet on the north and east. The northern part of the flats is made up of gently sloping outwash fans of the Chandalar, Christian, and Sheenjek Rivers; the southeastern part of the flats is the broad gentle outwash fan of the Yukon River. Other areas are nearly flat flood plains. Four thousand seven hundred square miles of rolling silt- and gravel-covered marginal terraces or uplands, having sharp escarpments 150-600 feet high, rise above the

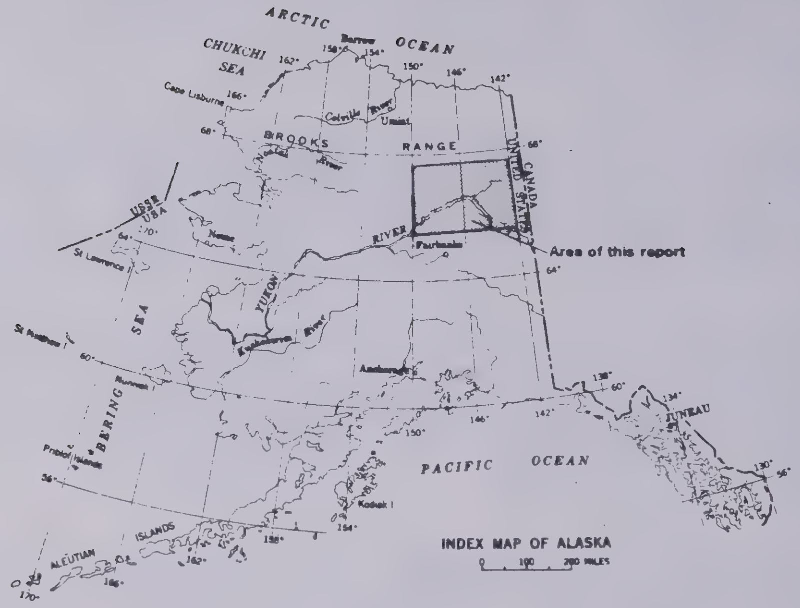


Figure 23. Index map of Alaska showing Yukon Flats district. (Source: Williams, 1962, U.S. Geol. Survey Bull. 1111-H, p. 290.)

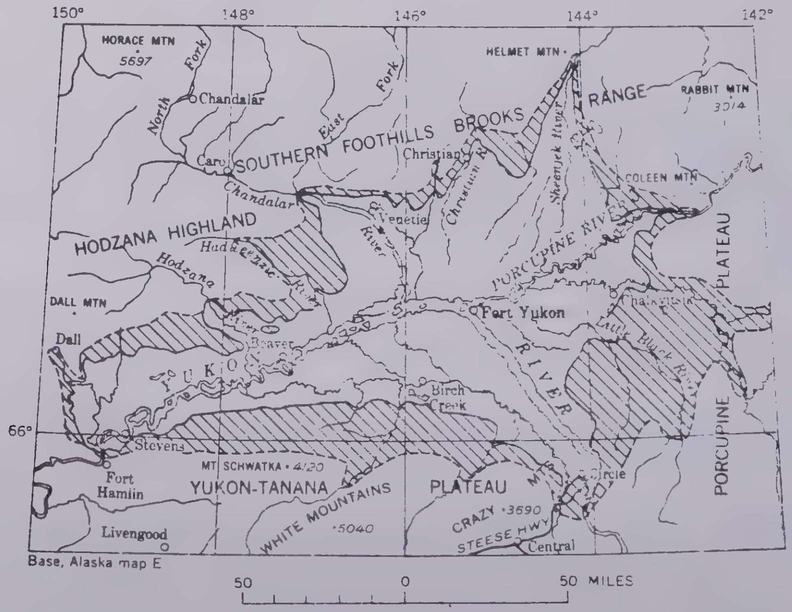


Figure 24. Physiographic subdivisions of the Yukon Flats district. Marginal upland (diagonal lines) and Yukon Flats (stippled). Boundary of district shown by dashed lines. (Source: Williams, 1962, U.S. Geol. Survey Bull. 1111-H, p. 291.)

flats and slope gradually upward to altitudes of 1,000 to 1,500 feet at the base of surrounding highlands and mountains (Wahrhaftig, 1965, p. 25).

The Yukon Flats section is drained by the Yukon River, which has a meandering, braided course southeast of the bend at Fort Yukon. Most tributaries rise in surrounding uplands and mountains and have meandering courses through the flats.

Escarpments bounding the Yukon Flats expose well-consolidated or crystalline rocks of Paleozoic and possibly Mesozoic age. Extensive acidic intrusives crop out north and southeast of the basin. The marginal uplands are capped with gravel on which rests a layer of windborne silt. A well drilled at Fort Yukon in 1954 disclosed 48 feet of aeolian sand of late Pleistocene or Recent age, underlain by 100 feet of sandy gravel of Pleistocene age, underlain in turn by at least 292 feet of fine lake sediments of late Pliocene or early Pleistocene age. On the basis of this well it is thought that the Yukon Flats are the site of a late Tertiary lake that occupied a downwarped basin (Wahrhaftig, 1965, p. 25).

The Yukon Flats district is generally the warmest in summer and coldest in winter of any place in Alaska. The mean temperature in July at Fort Yukon is 64°F and throughout the district averages 62°F. The mean temperature in January at Fort Yukon is -19°F and throughout the district averages -17°F, and the yearly average temperature is approximately 23°F (Searby, 1968). Fort Yukon has an average of 6.52 inches of precipitation per year. The maximum depth of permafrost in the flats is 390 feet. The fine-grained sediments in the uplands have permafrost to 600 feet. The coarser-grained upland sediments and highlands to the east, west, northwest, and south have discontinuous permafrost, whereas those to the north have continuous permafrost (Ferrians, 1965). The best reference and geologic map of the region are included in the Geologic Reconnaissance of the Yukon Flats District, Alaska, by John Williams, 1962.

Sedimentary Rocks

The Yukon Flats Cenozoic basin can be divided into a shallow part and a deep part along a boundary which in most places follows a marginal escarpment 100 to 500 feet high, probably caused by downfaulting (figs. 25, 26). The shallow part of the Cenozoic basin, which occupies the marginal upland, has many exposures of pre-Cenozoic rocks along gullies and the marginal escarpment. These rocks are covered in a few areas by lower Tertiary nonmarine sediments and volcanics, but in most of the marginal upland, high-level alluvial deposits of late Tertiary or early Quaternary age cover the pre-Cenozoic rocks. The high-level alluvium in turn is covered by Pleistocene, and possibly locally Recent, loess and eolian sand.

The deep part of the Cenozoic basin coincides approximately with the Yukon Flats. A water well drilled at Fort Yukon provided information on the unconsolidated sediments to a depth of 440 feet. Pleistocene and Recent gravel, sand, and silt similar to that of the present-day alluvial fans, river terraces, flood plains, and sand dunes are 148 feet thick. These are underlain by about 290 feet of Tertiary silt, silty sand, and peat.

Fossils have indicated the 290-foot layer is no younger than middle to late Pleistocene (Williams, 1962, p. 321), but may be as old as Eocene:

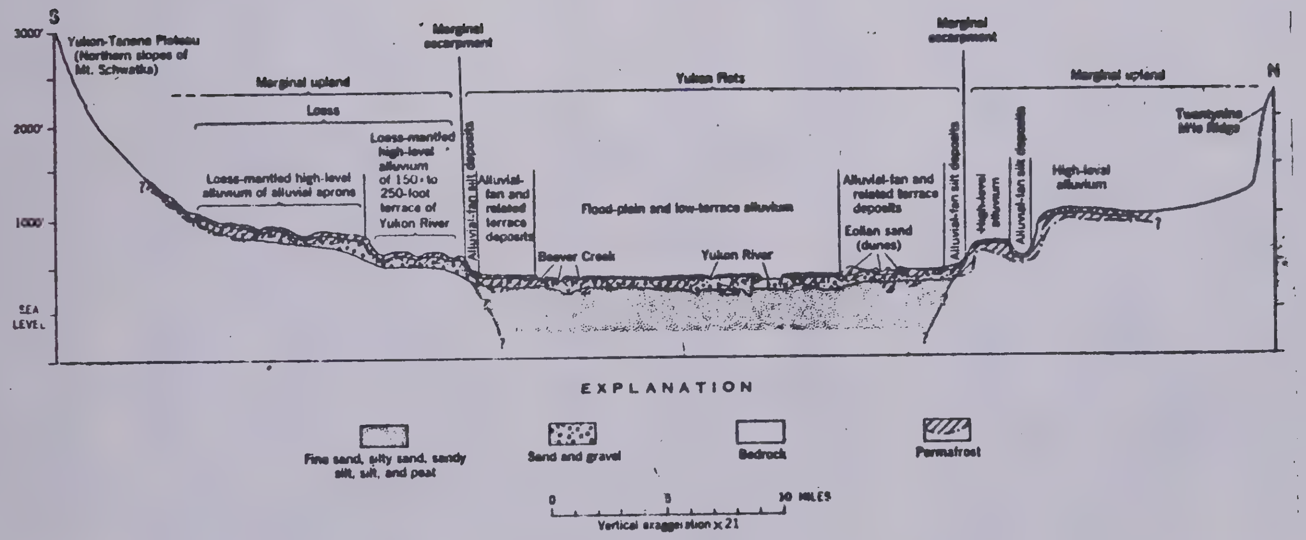


Figure 25. Diagrammatic section through Yukon Flats district between Mile Ridge and Yukon-Tanana Plateau showing geologic units and permafrost. (Source: Williams, 1962, U.S. Geol. Survey Bull. 1111-H, p. 296.)

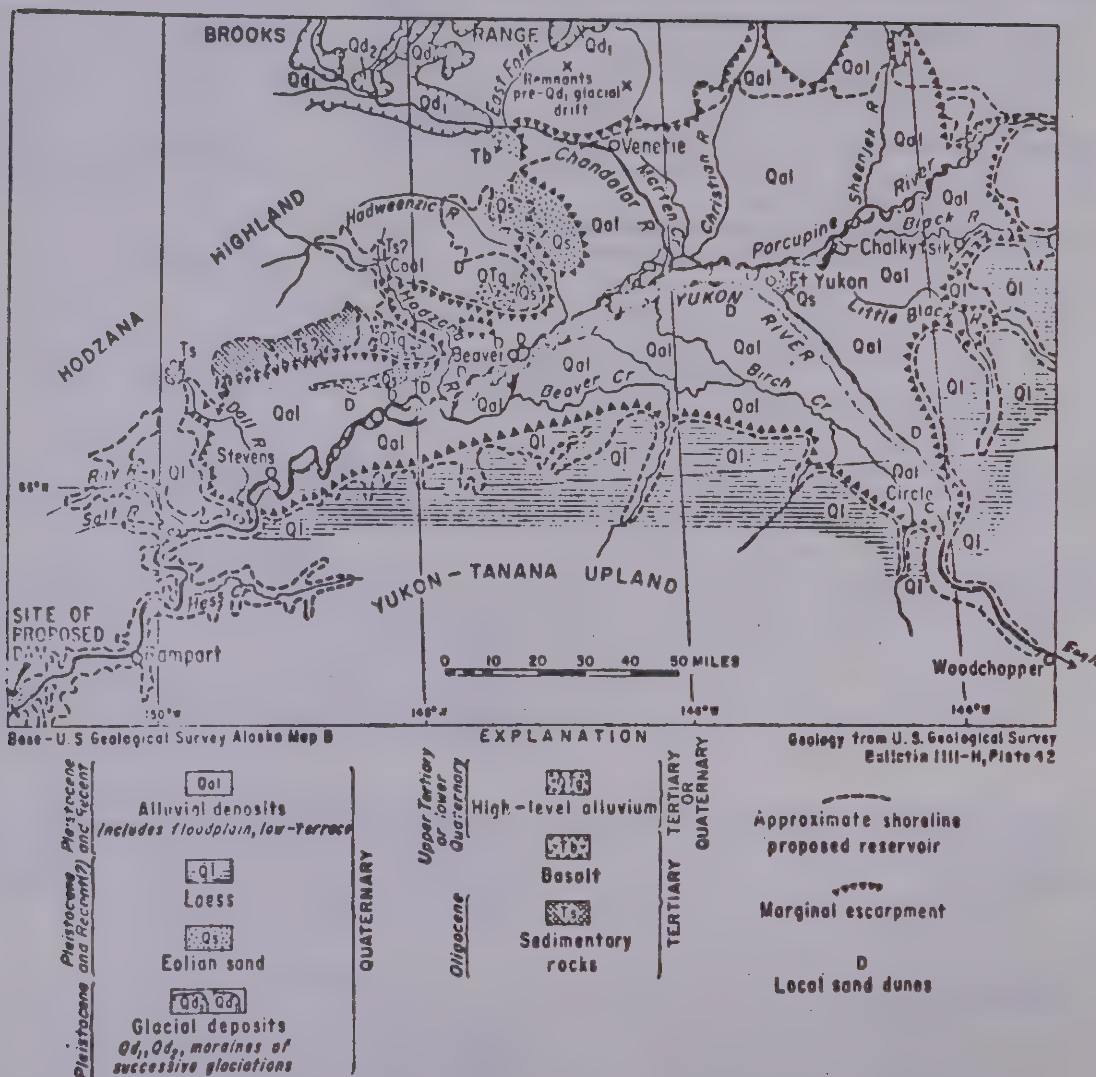


Figure 26. Generalized geology, Yukon Flats Cenozoic Basin (Source: Williams, 1962, U.S. Geol. Survey Bull. 1111-H, pl. 42.)

Driller's log, Fort Yukon water well No. 2 (drilled Aug. 7 to Oct. 1, 1954, by Alaska District, Corps of Engineers, U.S. Army, at site about half a mile east of the village).

Depth (feet)	Driller's log of materials	Permafrost (depth in feet)	Writer's interpretation
0-48	Light-tan silty sand - - - - -	8-48	Pleistocene and Recent dune sand
48-148	Gray sandy gravel	48-148	Pleistocene alluvium of Yukon alluvial fan
148-320	Blue silt- - - - - - - - - - - -	148-320	
320-390	Gray silt, poorly consolidated, few ice lenses	- - - -	Lacustrine(?) deposits of late Tertiary or
390-425	Silty sand, 85 percent passing No. 100 sieve, 15 percent	- - - -	early Quaternary age
425-440	Silt -		Williams (1962, p. 303)

Sedimentary Rocks of the Yukon
(from Williams (1962); Brosge, Reiser, Yeend (1973); and Payne (1955)

Holocene	Surficial deposits Alluvium, loess, and eolian sand
Upper Tertiary or Lower Quaternary	High Level Alluvium Stratified gray to blue-gray to rusty-brown well-sorted pebble to boulder gravel with minor amounts of sand and silt. Particles slightly cemented and stained by iron oxide. Maximum thickness not known, but locally exceeds 100 feet.
Upper Tertiary (more likely) or Lower Quaternary	Lacustrine(?) deposits Stratified gray and blue poorly consolidated silt and silty sand. Minimum thickness at Fort Yukon is 292 feet. Thickness and extent unknown elsewhere.
Eocene-Pliocene?	Sedimentary rocks Yellow and gray, thin-bedded water-lain tuff and siltstone; quartz-pebble conglomerate with a soft sandy matrix; and amber-bearing coal in beds as much as 5 feet thick. Only about 100 feet exposed. Tuff and siltstone contain Tertiary pollen of probably Miocene age at fossil locality 1. Coal is of subbituminous rank according to analyses by U.S. Bureau of Mines.

According to Williams (1962), it is very possible that relatively extensive moderate dipping Tertiary deposits of nonmarine lignitic and tuffaceous sandstones, conglomerates, and siltstones may underlie the northwestern part of the Yukon Flats uplands. Deposits of similar description occur on the Dall and Hodzana Rivers, northern tributaries to the Yukon River (Williams, 1962; Brosge, Reiser, and Yeend, 1973). The intervening rock appears stratified, is reasonably well indurated, and forms hills. These qualities are also possessed by nearby known Tertiary sediments, but not by most Quaternary sediments in the area. The greater portion of the area between the Dall and Hodzana Rivers has not been examined in the field, and the extent of the Early Tertiary deposits there is unknown. Mapping of the stratified rock between the Dall and Hodzana Rivers has been by areal photographs. Sediments were identified as the same Quaternary gravel and sand excamined in the field 20 miles away near the confluence of the Hodzana and Yukon Rivers.

According to Paige (1959) and Chapman (personal communication), the Early Tertiary sandstones, conglomerates, and siltstones are difficult to identify because they do not form good outcrops. From the air it would be difficult to differentiate Tertiary from Quaternary sediments and 30 miles is too far to extrapolate rock ages and types. Therefore, no final conclusion can be drawn as to the age or type of stratified rock.

Tertiary sediments commonly occur in topographic lows along and near the Yukon River. The areal extent, similarity, and proximity of the deposits to the Yukon Flats uplands support the supposition that similar deposits could occur between the outcrops on the Dall and Hodzana Rivers. The Tertiary sediments that are on the north bank of the Yukon 15 miles north of Rampart, on the east bank 2 miles north of Rampart, and on the north bank at and near the Drew coal mines probably are outcrops of the same 100+ square-mile deposit that is mostly covered by Quaternary sediments. Jack Wolff of the U.S. Geological Survey (personal communication, 1974) stated that the Tertiary sediments at the Drew mine and Rampart area form an essentially complete section from Eocene through Pliocene. The outcrops in the Livengood quadrangle are described by Chapman, Weber, and Taber (1971) as follows:

> <u>*Sandstone, siltstone, conglomerate, and coal*</u>*.--Non-marine clastic rocks, dominantly arenaceous and rudaceous, light to medium greenish gray to gray, weather light and medium yellowish brown and brown, poorly to well consolidated, friable. Commonly have calcareous cement, some ironstone nodules, lenses, and thin layers, and plant fossils and fragments. Conglomerates are locally derived and the pebbles, cobbles, and less-common boulders range greatly in composition, angularity, and size. Siltstone and shale are less common. Lignitic shale, bituminous coal, and associated thin clay layers are present in minor amounts. Coal beds probably do not exceed 7 feet, and generally are 2 feet or less, in thickness. Plant fossils from the Drew Mine locality are Eocene; some Paleocene and (or) Oligocene rocks may also be present here and elsewhere. Thickness is about 5,000 feet at Drew Mine locality, and unknown elsewhere.*

Chapman and Yeend (1972) describe the outcrops near Rampart, the outcrops of a deposit of at least 50 square miles (Chapman, 1974, personal communication) that is partially covered by Quaternary sediments along the upper Tozitna River,

and the outcrops of a deposit of at least 30 square miles in the Cheyenne Creek area along the Yukon River, 25 miles east of Tanana:

Sandstone, conglomerate, and shale.--Interbedded sandstone and pebble-cobble-boulder conglomerate with some shale, siltstone, and lignite; light yellowish gray to medium yellowish brown, weather to various shades of yellowish to reddish brown, both poorly and well consolidated; non-marine, contain plant fossils in the river bluff near Rampart (Mertie, 1937, p. 1972-180; MacNeil and others, 1961). Thickness probably several thousand feet but may vary considerably.

Paige (1959, unpublished report) mapped the Cheyenne Creek area thoroughly, but did not have time to map east of Jordan Creek. The Tertiary sediments probably do exist between Jordan Creek and Rampart to some extent, but may be mostly or completely buried by Quaternary sediments. The Tertiary sediments form a cliff face at water's edge on the west side of the Yukon River, south of Schieffelin Creek.

No mapping was attempted further to the west of the cliff, where more Tertiary sediments exist under Quaternary sediments. Paige's map descriptions of the Tertiary sediments are as follows:

Conglomerate--Buff to gray-brown, well-sorted, uniform pebble conglomerate with intercalated beds and lenses of tan, medium to coarse-grained sandstone. Pebbles consist mostly of quartz and chert. Cobbles more than 4 inches in diameter are rare.

Siltstone--Massive, black, arenaceous, well-indurated siltstone composed mostly of quartz and muscovite. Carbonaceous matter is abundant and consists of plant fragments that form a matted carbon film concentrated along poorly developed bedding planes.

There are two large (and several small) Tertiary and Late Cretaceous sedimentary deposits on the southeast edge of the Yukon Flats in the Kandik Basin-Eagle area as well as several small ones. The largest is about 80 miles long and 1 to 15 miles wide and covers an area of 300 square miles northwest of Eagle along the Tintina Fault zone. The second largest is 20 miles long by 2 to 8 miles wide, covering an area of 100 square miles. There are small deposits on a tributary of the Kandik River near the Canadian border; on the Charley River; on Copper Creek; on Ruby Creek, a tributary of the Fortymile River; and on the Fortymile River in several outcroppings in the Chicken area. The small deposits range from 1 to 20 square miles in areal extent. Helen Foster (1972) describes the deposits south of 65° latitude as follows:

Detritial Rocks--Conglomerate, sandstone, mudstone, shale, breccia, tuffaceous rocks, and lignite. Conglomerate very coarse to fine and clasts poorly to well rounded. In the Eagle and Seventymile areas, well-rounded black chert pebbles are characteristic. Sandstone, mudstone, and tuffaceous rocks locally contain pollen and poorly preserved plant fragments and impressions. Map unit probably ranges in age from Late Cretaceous to Pliocene in the Eagle and Seventymile area. Probably early to late Tertiary in other parts of the quadrangle. Rocks have been folded and faulted.

Brabb and Churkin (1969) describe the deposits north of 65° latitude similarly:

> *Sandstone, mudstone, and conglomerate*--*Sandstone and conglomerate, poorly sorted, friable, composed mostly of lithic fragments and about 5 percent potash feldspar. Thin, lignitic coal beds common. Non-marine. Thickness 200 to at least 3,000 feet.*

The Tertiary sediments are not easy to recognize and are probably more widespread than presently mapped. Generally, only the conglomerate forms recognizable outcrops. Coal remnants and seams can sometimes be found. Fossils are rare and usually destroyed when eroded. When rock types other than coal and lignite are eroded from the Tertiary deposits, the resulting rubble is difficult to distinguish from Quaternary sediments. Most of the Tertiary sediments are covered by Quaternary sediments.

Igneous Rocks

The highlands surrounding the Yukon Flats basin contain many igneous intrusive and extrusive outcrops. In general, the basic igneous rocks are older and have a lower relief than the acidic igneous rocks. Most of the igneous rocks are intrusives or basalts. There are a few interbedded tuffs. Acidic igneous rocks have exposures of 1,700 square miles total in the Bettles, Beaver, and Chandalar quadrangles; 860 square miles total in the Eagle and Charley River quadrangles; and 315 square miles in the Coleen quadrangle. Basic and acidic igneous rocks were mapped together in the Yukon Flats generally in very small exposures. Basic igneous rocks are found in small to large exposures in the highlands. The basic rocks of the highlands, the igneous rocks of the Yukon Flats and the acidic igneous rocks of the highlands are each described below.

Igneous Rocks in the Yukon Flats

The following descriptions are from Williams (1962).

> *Basalt--Basalt and olivine basalt, locally amygdaloidal and porphyritic. Forms intrusive dikes and sills and extrusive flows. Tertiary in age.*

> *Sedimentary and volcanic rocks and associated intrusive igneous rocks--Quartzite, chert, crystalline limestone, chlorite schist or phyllite, shale, tuff and basalt, intruded by diorite, gabbro, diabase, quartz diorite, and granite. Mafic intrusive igneous rocks, tuff, and basalt generally of greenstone habit. Include Early Mississippian rocks of Rampart group near Fort Hamlin and Circle volcanics near Circle; and a chert-slate formation of Late Devonian age at Outlook Point. Most outcrops are exposed on the faces of the escarpments separating the highlands from the uplands and the uplands from the flats. Devonian and Carboniferous in age.*

> *Metamorphic rocks and associated intrusive igneous rocks--Quartzite, quartz-mica schist, and locally graphitic and calcareous schist, phyllite, and biotite schist. Minor beds of crystalline limestone. Intruded by granite, gneissic and porphyritic granitic rocks, and silicic dikes.*

Predominantly of pre-Devonian age, but include some rocks that may be correlated with Birch Creek Schist of Precambrian age and possibly some of Mesozoic age.

Basic Igneous Rocks of the Highlands

Most of the basic rocks are of Mesozoic and Paleozoic age and occur throughout the Yukon Flats district. Precambrian interbedded andesitic and greenstone basalts and tuffs are in the central and southeast corner of the Charley River quadrangle north of the Tintina Fault zone with an exposed area of 50 square miles and a thickness of a couple thousand feet. Greenstone tuffs are interbedded with the greenstone basalts of the several-thousand-foot-thick Devonian Woodchopper Volcanics in an area of 25 square miles. Scattered small deposits of Tertiary basalt occur along the Chandalar River and in the northwest and southeast quarters of the Livengood quadrangle. The southeast quarter of the Coleen quadrangle has 125 square miles of 300-foot-thick Cenozoic basalt flows. The Jurassic basalt, andesite, and gabbro occur in many small scattered exposures throughout the Coleen quadrangle and in the eastern half of the Christian quadrangle (Reiser, 1965, p. 68). The northwest quarter of the Livengood quadrangle has large exposures of Mesozoic basalt, andesite, and gabbro. Paleozoic mafic and ultramafic rocks consisting of diorite, metadiorite, diabase, gabbro, basalt, metabasalt, greenstone, and serpentinite occur in a wide swath across the middle of the Livengood quadrangle from the northeast corner to the southwest corner.

Acidic Igneous Rocks of the Highlands

The acidic igneous rocks are mostly Cretaceous intrusives of granite and quartz monzonite with some quartz diorite. Extensive complexes lie north and west of the west end of the Yukon Flats, southeast of the village of Circle, and at the Canadian border on the Porcupine River. A few minor plutons crop out to the south of the Yukon Flats in the Livengood and Circle quadrangles. According to Florence Weber (personal communication), the gneisses in the Charley River quadrangle south of the Tintina Fault zone were probably originally Paleozoic acidic intrusives. A Tertiary or Cretaceous (or both) rhyolitic tuff formation lies between the Kanuti granitic pluton and the Tertiary stratified sedimentary rocks north of the Yukon River and in the Beaver quadrangle.

Brosge, Reiser, and Yeend's (1973) description of granitic rocks and contaminated granitic rocks are for the same rocks as Brosge and Reiser's (1964) granitic rocks and migmatite descriptions, respectively.

Bettles and Beaver quadrangles northwest of Yukon Flats
(from Brosge, Reiser, and Yeend, 1973)

Rhyolite--Gray, brown, pale-red and orange porphyritic rhyolite, welded rhyolite tuff, and silicified laminated rhyolitic flows; minor amount of obsidian. Appears to overlie granitic rocks and may be intruded by them. Tertiary and/or Cretaceous in age. Rectangular body of 50 square miles areal extent paralleling the Tertiary(?) sediments southwest of Lone Mountain.

Granitic Rocks--Porphyritic to granular, locally gneissic, quartz monzonite and granite; aplite; and a few pegmatite dikes. Includes diorite near contact on upper Dall River. Cretaceous in age. Areal extent of 600 square miles in eastern third of Bettles quadrangle and 550 square miles in northwestern quarter of Beaver quadrangle.

Contaminated Granitic Rocks--Dark fine- to coarse-grained granitic rocks with abundant mafic schlieren composed of amphibole, plagioclase, epidote, sphene, apatite, and minor quartz. Small body of eight square miles next to granitic rocks at northern edge of the quadrangle. Cretaceous in age.

Chandalar quadrangle
(from Brosge and Reiser, 1964)

Granitic Rocks--Gneissic chloritized biotite granite, quartz, monzonite and granodiorite having an extent of 70 square miles to the west and 10 square miles to the east of Sixty-One Mountain near the southern edge of the quadrangle and 170 square miles in the center of the quadrangle. Some gneissic chloritized hornblende granite and granodiorite with secondary epidote and calcite along northwest margin of Geroe Creek pluton, in sill through Horace Mountain and at Our Creek grades locally to closely foliated chloritic granite gneiss. Includes some biotitic quartzite southwest of Caro. Mesozoic in age.

Granitic Rocks--In Monarch Creek-Keating Creek area; hornblende-biotite granodiorite and quartz monzonite; some granite; commonly porphyritic, with potash feldspar phenocrysts; small inclusions of dark, fine-grained hornblende-biotite granodiorite and diorite and biotite-hornblende-pyroxene andesite. In Chuttoh Bluffs area: porphyritic biotite-hornblende granite and quartz monzonite; many aplite dikes. Seems gradational with adjacent gneissic granite. Extends across 900 square miles of the southern sixth of the quadrangle. Mesozoic in age.

Migmatite--Granitic rocks intercalated with biotite schist and some hornblende hornfels; pyroxene hornfels and granitic dikes at Chuttoh Bluffs. Partially intermingles with and surrounds granitic rocks with an areal extent of 120 square miles. Mesozoic in age.

South of Tintina Fault in Charley River and Eagle quadrangles
(from Foster, 1972)

Felsic Igneous Rocks--Tuffs, welded tuffs, volcanic breccia, and felsic shallow intrusive rocks, including porphyries, as dikes, sills, and small bodies. Dikes and masses of felsic igneous rocks too small to map, common in other units. Rocks of this unit commonly much altered and weathered; white, gray, pink, light brown, or orange brown in color. Glassy rocks are dark gray or green. Probably Tertiary in age. Small outcrops scattered in clusters through eastern half of Eagle quadrangle with a total area of about 150 square miles.

Intermediate Volcanic Rocks--*Lava, volcanic breccia and tuff. Tan, gray, or greenish gray. Altered and weathered. Probably Tertiary in age. Two outcrops of 8 square miles total extent on Kechumstuk Creek near Kechumstuk Mountain near the southern edge of the Eagle quadrangle.*

Diorite--*Primarily diorite, quartz diorite and diorite porphyry, but may include some granodiorite or gabbro. Only larger bodies indicated. Gray diorite and quartz diorite also occurs commonly in other igneous units. Mesozoic and Tertiary in age. Scattered occurrences mainly in southeastern half of Eagle quadrangle with 40 square miles exposed.*

Undifferentiated Granitic Rocks--*Primarily quartz monzonite and granodiorite, but includes granite to diorite with local aplite, alaskite, and pegmatite. Fine to coarse grained; equigranular to coarsely porphyritic. Biotite-hornblende granodiorite abundant. Commonly crops out in tors. Most of larger plutons probably Mesozoic in age but includes Tertiary plutons. South of Tintina Fault Zone 150 square miles in Charley River quadrangle, most of the northwestern half of Eagle quadrangle, and 300 square miles of plutons decreasing in size and quantity to the southeast in the southeastern half of the Eagle quadrangle.*

Hornblende Granodiorite--*Primarily coarse-grained hornblende granodiorite and quartz monzonite but includes some gabbro and syenite. Probably Mesozoic in age. Several small outcrops in a northeast-southwest line covering 30 square miles in the center of the Eagle quadrangle.*

Syenite of Mount Veta--*Primarily hornblende syenite porphyry, but locally equigranular. Includes hornblende quartz-monzonite and diorite. Jurassic in age. A cluster of outcrops around Mount Veta delineating a deposit of 50 square miles areal extent.*

Granodiorite of Taylor Mountains--*Medium- to coarse-grained granodiorite of Taylor Mountain batholith. Locally includes quartz monzonite, quartz diorite, and some diorite. Includes lamprophyre dikes. Eastern margin is gradational with zones where much country rock has been incorporated; dikes are abundant and country rock is locally hornfelsed and brecciated. Jurassic and/or Triassic in age. Plutons outcropping as Taylor Mountain and hills immediately to the east extending 130 square miles.*

Silicified Tuff(?)--*White, light tan, or light gray, structureless, massive silicic rock. Probably metamorphosed tuff. Age unknown, but probably Mesozoic or Paleozoic. Three small patches with total area of one square mile on King Solomon Creek, a tributary of the Fortymile River.*

Biotite Gneiss and Amphibolite--*Quartz-biotite gneiss and schist, amphibolite, quartzite, marble, and feldspathic gneiss. Abundant garnet and rare staurolite, andalusite, sillimanite, and cyanite. Age uncertain, but probably mostly Paleozoic, but could include rocks and metamorphisms of Precambrian age. An areal extent of 1,040 square miles*

mainly in the southeast corner of the Eagle quadrangle with scattered exposures in and next to the Tertiary and Mesozoic granitic rocks throughout the Eagle and Charley River quadrangles south of the Tintina Fault Zone.

Augen Gneiss--Quartz-biotite augen gneiss, quartz-biotite gneiss, amphibolite and quartzite. Probably mostly amphibolite facies. Age uncertain, probably mostly Paleozoic but could be all or partly Precambrian. Mainly one body near the southwest corner of the Eagle quadrangle with an areal extent of 110 square miles.

Mylonite and Mylonite Gneiss--Primarily mylonite and mylonite gneiss; mostly gneissic in appearance; includes augen gneiss. Age uncertain but probably mostly Paleozoic and (or) Precambrian. Five outcrops with a total areal extent of 50 square miles around the confluence of Charley River and Copper Creek in the northwest corner of the Eagle quadrangle.

Gneiss and Granitic Rocks, Intermixed--Quartz-biotite gneiss, feldspathic gneiss and quartzite, mixed with granitic rocks. Outcrops rare, mostly rubble. Appears to be amphibolite facies but metamorphic rocks complexly intruded and mixed with granitic rocks. Metamorphic rocks of uncertain age, but probably mostly Paleozoic and (or) Precambrian. Intermixed granitic rocks of Mesozoic and Tertiary age. Scattered outcrops of 120 square miles total areal extent along west edge and center of Eagle quadrangle.

Gneiss and Hypabyssal Rocks, Intermixed--Quartz-biotite gneiss, feldspathic, gneiss and quartzite intermixed with felsic hypabyssal and volcanic rocks and some granitic rubble. Outcrops rare, mostly rubble. Felsic rocks are from dikes, sills, and erosional remnants of volcanic rocks. Metamorphic rocks of uncertain age, probably Paleozoic and (or) Precambrian. Felsic rocks probably of Tertiary age. Granitic rocks probably Mesozoic and (or) Tertiary in age. Small body of 20 square miles extent in the southwest corner of the Eagle quadrangle.

Northeastern Coleen quadrangle
(from Brosge and Reiser, 1969)

Rhyolite--Sills peripheral to granite intrude rocks as young as Mississippian. Extent of 15 square miles along southern edge of granite near Canadian Border. Upper Paleozoic(?) in age.

Granite--Biotite granite and quartz monzonite with minor muscovite locally; partly porphyritic. Carboniferous in age.

Structure

The known Tertiary rocks in this region have undergone little deformation. Because the flat-lying rocks observed on areal photographs on the northwest border of the Yukon Flats have not been visited in the field and because the age, composition, deformation, and thickness of the sediments under the basin are not completely known, the structure of the basin can only be theorized.

The flat-lying rocks on the northwest edge of the Yukon Flats may be an extension of the Rampart and Eagle Early Tertiary trough deposits. They may extend beneath the Quaternary cover. They do not appear to have been as deformed by the Miocene deformation as the Rampart Early Tertiary rocks southeast of the basin (Williams, 1962, p. 321).

The other continental deposits of the Yukon Flats district represent either (a) remnants of a former extensive cover of sediments that have been preserved by post-Oligocene (Williams, 1964, p. 6) downfaulting or downwarping, or (b) deposits accumulated as the troughs and basins that originated during a phase of the Laramide disturbance (later Paleocene or post-Paleocene) continued to subside (Williams, 1962; p. 320). The marginal escarpments that separate the Yukon Flats from the uplands seem to support the downfaulting theory.

Interpretations of aeromagnetic surveys by different people have resulted in conflicting conclusions as to the types and thicknesses of materials underlying the Yukon Flats. Brosge, Brabb, and King (1970, p. 10) believe aeromagnetic anomalies indicate the depth of the sediments in the Flats is not great. They state that the sediments are probably underlain at a relatively shallow depth by Paleozoic or Mesozoic volcanic rocks and overlain at a shallow depth by mafic volcanics:

> *The mafic rocks in the Yukon Flats are shown on the map (pl. 1) to be widespread. All are grouped in a single general category in the absence of exposures other than the volcanics on the margins. Most of the magnetic anomalies could be caused by sheets of volcanic rock at a shallow depth overlying or within a sedimentary sequence. Two high-amplitude anomalies, one at 143° - 144° (6) and one west of 147° (7), indicate the presence of more massive bodies of possibly more magnetic rock; they may indicate source areas for the extrusive materials.*
>
> *The Yukon Flats area was considered a possible petroleum province in a sedimentary basin of Tertiary age by Miller, Payne, and Gryc (1959, p. 87-88). The aeromagnetic profiles suggest, on the contrary, that the Paleozoic or Mesozoic volcanic rocks that are exposed around the periphery of the Yukon Flats probably extend beneath the flats at relatively shallow depth (Sietz and others, 1960). A magnetic low (8, pls. 1 and 3) occupies the Porcupine Plateau just east of the flats and could represent the thickest section of sedimentary rocks. However, reconnaissance of the Black River area (Brabb, 1969), indicates that the rocks in the vicinity of the magnetic low are probably Paleozoic or Precambrian rather than Tertiary and are outside the basin.*

Barnes (1971, p. 7-8) analyzed Bouguer gravity anomalies of the Yukon Flats district and decided the Yukon Flats represent a deep Cenozoic sedimentary basin. Similar studies of the Minto and Noatak Flats indicate a sediment thickness of 1 to 3 kilometers. Barnes' conclusions are listed below:

> *(L) A local gravity low southwest of the big bend in the Black River is associated with an outcrop and probably erruptive center for Cenozoic volcanics. This gravity low thus suggests that these volcanic rocks may be vesicular and have low densities. The author believes that the combined gravity and aeromagnetic characteristics of many of the geophysical anomalies mapped in the alluvial covered parts of the Yukon Flats resemble the geophysical characteristics of the Cenozoic volcanics which might thus partly overlie sedimentary rocks.*

(M) Low Bouguer gravities measured in the Yukon Flats are now believed to represent Cenozoic basins, which may or may not be connected or continuous. The gravity lows are similar in magnitude and area to other lows which have been observed in Alaska at Minto Flats (Barnes, 1961), Noatak Flats (Barnes and Tailleur, 1970) and along the middle Tanana River (Barnes, 1969) and which are believed to represent Cenozoic basins. The low in the Yukon Flats may be the largest in area but its magnitude suggests a comparable thickness of sediments.

(Q) Both high Bouguer gravities and high densities have been measured near outcrops of the Permo-Triassic Circle and Rampart volcanics, which are now considered to be largely intrusive (Churkin, 1970). High gravities have not been found in parts of the Yukon Flats which are covered by surficial deposits. Therefore, these rocks are not believed to be the cause of the shallow-depth aeromagnetic anomalies measured over the flats (Brosge and others, 1970).

Economic Geology

The highlands surrounding the Yukon Flats district contain four gold mining districts: Livengood, Circle, Eagle, and Chandalar. According to Williams (1962), numerous reports have been made of traces of placer gold in the alluvium of the Yukon Flats district, but to date no significant deposits have been found. Three of the mining districts have drainages into the Yukon Flats and could therefore contribute to the deposition of uranium. Drainage from the Livengood mining district empties into the Yukon River below the Yukon Flats and probably has had no effect on the area. Nearly all of the Circle mining district drains directly into the southern flats. The Eagle mining district's drainage empties into the Yukon River just above the Yukon Flats. The section of the Chandalar mining district that is drained by the tributaries of the Chandalar River drains into the northern Yukon Flats. The other section drains into the Yukon River below the flats.

Livengood Quadrangle

There are four gold placers and one gold and one silver lode that are drained by rivers leading into the Yukon Flats. No uranium-bearing minerals have been reported (USGS circulars 331 and 335). Nome Creek and Wickersham Dome have currently active claims (Heiner and Wolff, 1968).

Circle Quadrangle

Fourteen of 34 gold placers and four of five lodes in the Yukon Flats drainage contain other elements of possible economic importance (Cobb, 1972), including tungsten, tin, and lead. The lode on Bedrock Creek and the placers on Nome Creek and Portage Creek contain monazite. The placers on Independence, Mammoth, Ketchem, and Portage Creeks have minerals (other than monazite) that contain rare-earth metals. Portage Creek also contains small amounts of uranothorianite and a yellow-green nonfluorescent uranium mineral. Deadwood and Portage Creeks both contain fluorite (Heiner and Wolff, 1968). Mammoth Creek was a very large producer of gold.

Eagle Quadrangle

The 15 lodes and 82 placers of this quadrangle are drained by rivers flowing north and east to the Yukon River above the Yukon Flats (Cobb, 1972). Ten of the lodes and 72 of the placers were mined or prospected, mainly for gold. Other primary and secondary elements of economic interest are silver, lead, tungsten, mercury, platinum, and copper. Placers along Copper, Excelsior, Mission, Wolf, American, Ben, Slate, and Ruby Creeks and the Atwater Creek fork of the Mosquito Fork of the Fortymile River contain monazite. Ben, Slate, and Ruby Creeks have minerals containing rare-earth metals besides monazite. Copper Creek, a tributary of the Charley River, has a lode in a metamorphic roof pendant that contains a small amount of uranium (Berg and Cobb, 1967, p. 210). A placer on Atwater Bar has uranium-bearing thorium (Wedow and White, 1954, p. 10, 11).

Charley River Quadrangle

Two lodes and 16 placers are drained by tributaries that join the Yukon River above the Yukon Flats (Cobb, 1972). All the placers are for gold; two contain platinum alloyed with the gold. Gold has been produced from most of the placers. All but one of the placers (Drayham Creek) are related to the Upper Cretaceous and Early Tertiary nonmarine sedimentary unit along the Tintina Fault zone. This unit will be discussed later. The lodes consist of copper mineralization on a small peak to the west of the head of Fisher Creek, and iron in the rock between the Tatonduk River and Squaw Mountain.

Coleen Quadrangle

There are one gold and one nickel deposit reported (Heiner and Wolff, 1968). The nickel is in a nickel-bearing alum. No production is known from either deposit.

Chandalar Quadrangle

Of 18 lodes and seven placers in the section of the quadrangle that drains into the Yukon Flats, only two lodes and three placers have gold alone reported as a commodity (Cobb, 1972). There are six lodes containing only copper and two containing gold and silver. Eight lodes, about 12 miles northeast of Chandalar, have antimony, copper, gold, lead, silver, and zinc. The placers in the area of these eight lodes generally contain gold, lead, monazite, and tungsten.

Name of Placer Deposits	Commodity
Tobin Creek	Au, Pb, Mz, W
Big Creek	Cu, Au, Pb, Mz, W
St. Marys Creek	Au
Big Squaw (Squaw) Creek	Sb, FM, Au, Pb, Mg, Mz
Little Squaw Creek	Au, Pb, Mz, W

Legend:
Au - gold   Mz - monazite   Cu - copper   Mo - molybdenum
Pb - lead   W - tungsten   Sb - antimony
FM - fissionable materials (other than monazite)

The Big Squaw Creek placer contains trace amounts of uranothorianite (Heiner and Wolff, 1968, p. 47). The placers and lodes in the Big Creek-Squaw Creek area contain arsenopyrite, sphalerite, pyrite, and galena. There has been recorded production of gold from two of the lodes, and gold has been produced from most of the placers.

Beaver Quadrangle

There are three deposits on Trout Creek, one of which is a gold placer at the mouth of Trout Creek, where it joins Slate Creek. Another was listed by Cobb (1972) as a molybdenum and zinc lode, and the third by Heiner and Wolff (1968) as a zinc, molybdenum, and gold placer with pyrite, sphalerite, and molybdenite.

Fort Yukon Quadrangle

There are three types of deposits, none of which have produced (Heiner and Wolff, 1968). Potash from the potash salts of several lakes is not of economic value. One gold placer and a gold-and-silver lode on the Yukon River have not been worked.

Williams (1962) describes the coal resources of the Yukon Flats as follows:

> *Lignitic coal occurs on Dall River and its tributary, Coal Creek, and subbituminous coal occurs on the Hodzana River near the forks. Coal or lignite may be included in the flat-lying sedimentary rocks between Dall and Hodzana Rivers if these rocks are equivalent in age to the coal-bearing rocks of the Dall and Hodzana River. The only available analysis is of coal collected from bars of the Hodzana River downstream from the outcrop and submitted to Alaska Railroad through the Territorial Assay Office by N.C. Ross of Beaver (Alaska Railroad analysis No. 9,299 dated Nov. 14, 1942).*

Radioactivity Investigations

Results of investigations along roads and navigable rivers and mineral analyses of mine samples in the Yukon Flats and surrounding highlands are summarized.

Upper Chatanika Valley Area

Two investigations for radioactive material were conducted in this area (Wedow, Killeen, and others, 1954, p. 8-9). The only significant radioactivity encountered was in concentrates from Nome Creek, where the maximum eU found was .026 percent during the first study and 0.012 percent during the second.

Hope Creek-Miller House-Circle Hot Springs Area

In a 1949 study of Hope Creek by White and Toblert (Wedow, White, and others, 1954, p. 7-15), concentrates had eU contents of 0.005 to 0.007 percent, apparently

due mainly to uranium. A 1952 study by West and Matzko (Nelson, West, and Matzko, 1954, p. 7-15) found equivalent uranium percentages from less than 0.001 to 0.005 in all 22 test sites in the Hope Creek area and in 44 of 46 test sites in the Miller House-Circle Hot Springs area. Granite talus on a ridge between the south and middle headwater forks of American Creek, a tributary of Preacher Creek, contained an eU percentage of 0.005. A placer on Portage Creek provided a size fractionated sluice box concentrate of 0.091 percent eU. The radiation was due mostly to uranothorianite. Of eight water samples collected in the Miller House-Circle Hot Springs area, only one was unusually high in uranium. It contained 40.2×10^{-7} percent, compared with the average of 1×10^{-8} for fresh waters. This is about 40 times more uranium than the other seven water samples.

Very little exploration of this several-square-mile roof pendant was undertaken (Wedow, White, and others, 1949, p. 7-9). The few samples gathered were all within a few feet of the most highly radioactive spot of the copper prospect. The highest eU of an unconsolidated sample was 0.032 percent. The radiation was due nearly entirely to uranium associated with bornite and malachite.

Yukon Flats

Freeman (1963, p. 32) reported on the examination of a prospect on Bedrock Creek, about 4 miles east of Miller House. At the prospect, a zone of iron-stained schist in the Birch Creek Schist bedrock gave a radiometric reading of 0.05 mr/hr, compared with a reading of 0.01 mr/hr in schist away from the location.

Some of the concluding statements regarding the uranium possibilities in the Miller House-Circle Hot Springs area are quoted from Nelson, West, and Matzko (1954, p. 14-15):

> *A wide variety of radioactive minerals were found to occur in granite. Certain uranium-bearing minerals in the Miller House-Circle Hot Springs area, which are also believed to contain uranium in the Hope Creek area, appear to be primary accessory minerals in the granite. Other minerals, such as fluorite, topaz, and several metallic sulfides in both areas, and cassiterite and wolframite in the Miller House-Circle Hot Springs area, were probably formed as a result of pneumatolytic action after the crystallization of the magma or during the late stages of crystallization. Some of the minerals in the latter group are known to be uranium bearing; therefore, it seems likely that hydrothermal solutions were partly responsible for the introduction of uranium during the process of pneumatolysis.*
>
> *On the basis of present information, the Hope Creek area does not appear to be favorable for the occurrence of high-grade uranium ores. It should be pointed out, however, that the work done in 1952 consisted only of a brief reconnaissance primarily intended to locate and test reported fluorite occurrences. Prospectors searching the area for other metals should keep in mind the possible association of uranium with mineralized zones containing hematite of hydrothermal origin, with minerals containing silver, cobalt, nickel, bismuth, and fluorine, and to a lesser extent with lode deposits containing copper, tin, lead, molybdenum, and gold.*
>
> *...On the other hand, this area, particularly the watershed of Portage Creek, cannot be ruled as unfavorable for the occurrence of uranium in lode deposits, because of the relatively high uranium content of water and the presence of uranothorianite in concentrates from Portage Creek.*

Upper Porcupine and Lower Coleen Rivers

Unconcentrated samples of crushed Precambrian rocks, Silurian, Devonian, and Carboniferous black shales, a Mesozoic granite mass and associated rhyolite dikes, Tertiary sediments, and stream gravels from entering tributaries along the Porcupine River ranged up to an eU of 0.006 percent (White, 1952). The samples of Middle Paleozoic shales along the Coleen River ranged up to an eU of 0.003 percent.

Chandalar District

Equivalent uranium values were reported by White (1952) and Nelson, West, and Matzko (1954, p. 15-19) using unconcentrated samples. White reported the following assays in percents of eu: Lake Creek, 0.017; Tobin Creek, 0.020; and at one spot on Big Creek, 0.050. Most of the radiation was attributed to monazite. Nelson found heavy mineral fractions at Tobin Creek containing 0.01 eU. The middle fork of Big Squaw Creek had 0.018 eU. The radiation in the Tobin Creek sample was due to trace amounts of monazite, while that of the middle fork of Big Squaw Creek was due to trace amounts of uranothorianite.

Fort Yukon to Fort Hamlin along Yukon River

The Quaternary deposits of silt, sand, and gravels and the Devonian or Carboniferous greenstone on the banks of the Yukon River near Fort Hamlin contain no anomalous radioactivity (White, Stevens, and Matzko, 1963, p. 82).

A part of a radiometric traverse along the Yukon River from Fort Yukon to Ruby by White, Stevens, and Matzko (1963, p. 83-87) produced the following results:

> *Three exposures of sedimentary rocks of Tertiary age were examined, and an exposure of quartz monzonite was tested. In the banks of the Yukon River opposite the mouth of Hess Creek, lignite is interbedded with thin-bedded shales and sandstone. The lignite has been mined locally and contains fossils determined to be of Eocene age (Eakin, 1916, p. 52). Conglomerate and grit tested in the area gave what were essentially background readings that indicated about 0.001 percent equivalent uranium or less; slightly higher readings were obtained from the lignite (table 7).*
>
> *Another outcrop of rocks of Tertiary age occurs on the east bank of the Yukon River and above Rampart. These beds include conglomerates, friable sandstones, clays, and thin seams of lignite and dark shales. They contain fossils identified as Eocene in age (Eakin, 1916, p. 52). No appreciable radioactivity was detected.*

Radioactivity of samples collected during the traverse of the Yukon River from Fort Yukon to Ruby, Alaska

File	*Description*	*Equivalent uranium (percent)*
	Tertiary deposits	
3401-----	*Conglomerate across from mouth of Hess Creek, on Yukon River.*	*0.001*
3402-----	*-----do-------------------------------*	*.001*
3403-----	*-----do-------------------------------*	*.001*
3404-----	*Conglomerate, south bank of Yukon River, upstream from Rampart.*	*.002*
3405-----	*-----do-------------------------------*	*.007*
3406-----	*-----do-------------------------------*	*.010*
3407-----	*-----do-------------------------------*	*.014*
3408-----	*-----do-------------------------------*	*.009*
3409-----	*-----do-------------------------------*	*.004*
3410-----	*-----do-------------------------------*	*.007*
3410a----	*-----do-------------------------------*	*.005*

The statement "no appreciable radioactivity was detected" does not seem to conform with the assays obtained from the Tertiary deposits. Equivalent uranium assays of 0.005 to 0.014 percent are significantly above the 0.001 values obtained and suggest that additional study of these rocks is needed.

Investigations for radioactivity by the writer (Eakins, 1969) were made along the Taylor Highway, in the vicinity of Eagle, and along the Yukon River short distances upstream and downstream from Eagle. The most significant findings follow:

> *Two feet of gouge in a fault zone in a conspicuous outcrop of marble in a road cut at Mile Post 114 gave three times the background count, or between 0.03 and 0.04 Mr/Hr. Tertiary sandstones and shales exposed in borrow pits along the Taylor Highway from a few miles south of Eagle to Eagle contain sandstone shales, and siltstones. The very fine-grained silty sandstones and siltstones were noticeably higher in radioactivity than the cleaner, coarser sandstones. Counts up to 0.03 Mr/Hr were obtained.*
>
> *A foot traverse along American Creek from Eagle south for five miles was made to examine Tertiary sandstones and conglomerates exposed in bluffs along the Creek. At three locations localized anomalies were encountered where faults cut these beds. The maximum readings were 0.03 Mr/Hr. Mission Creek enters the Yukon just west of the town of Eagle near the base of Eagle Bluff. The prominent Eagle Bluff stands between Mission Creek and the Yukon. In the 1940's several claims covering showings of gold, copper, nickel, and cobalt were staked along a fault zone on the Mission Creek side of Eagle Bluff. A foot traverse in this area did not produce any radioactive anomalies, but all seven claims were not examined in detail. No mining has been done on the claims.*

Frequent checks with counters along the Yukon River between Eagle and the Canadian border revealed no anomalies in the Paleozoic rocks exposed. The Nation River conglomerate exposed at points between two and eight miles downstream from Eagle produced no anomalous readings. The Mississippian Calico Bluff formation exposed on Calico Bluff about eight miles downriver from Eagle has been reported to contain radioactive black shales. The writer measured readings up to 0.05 Mr/Hr in black shales near the base of the bluff. A climb from the river to the top of the bluff produced lesser readings. Tertiary beds exposed on the south side of the Yukon from two to seven miles west of the mouth of the Seventymile River produced only very low radioactivity. A maximum reading of 0.05 Mr/Hr was obtained from one narrow brecciated zone cutting the beds.

Discussion

Little is known about the sediments in and around the Yukon Flats region. The favorable aspects, however, are that it is a large basin, has fresh water-lain sediments of probable Tertiary age, it is nearly closed by a bedrock bench at the lower end, and has tuffs and acidic volcanics in the sediments or in their drainage. The unfavorable aspects are the huge amount of water flowing in the Yukon River, the small amount of uranium found in the region, and the frozen ground which prevents water from percolating down from the surface.

More information is needed before uranium exploration can begin, particularly the depth of the sediments throughout the Flats. The age of the sediments, their lithology, permeability, facies changes, and dips all need to be identified through drill-hole sampling or geophysical methods. The possible presence of lava beds in the subsurface may complicate geophysical data interpretations.

The most interesting possible host rocks for uranium that crop out in the Yukon Flats district are the Early Tertiary sediments on the Dall and Hodzana Rivers and possibly the stratified rock in between. The Cretaceous Kanuti granitic pluton is up-drainage from the Tertiary sediments on the Dall River. The Cretaceous Hodzana granitic pluton and the Tertiary Cretaceous rhyolite and rhyolite tuff are up-drainage from the Tertiary sediments on the Hodzana River. The rhyolite and rhyolitic tuff on several tributaries of the Forks River are in the drainage area of the Tertiary(?) stratified rocks between the Dall and Hodzana Rivers.

No radioactivity studies have been conducted on the Tertiary sediments, and the nature of the stratified sediments between the Dall and Hodzana Rivers remains nearly completely unknown. The possibility that the sediments at and between the Dall and Hodzana Rivers could be economic uranium hosts is strong enough to warrant a more thorough geologic and radiometric investigation.

Uranium anomalies have been fairly well localized in the Miller House-Circle Hot Springs area, and the granitic intrusives should be investigated by geochemistry and modern radiometric devices to determine if uranium-bearing veins are present.

ALKALINE INTRUSIVE BELT OF WEST-CENTRAL ALASKA AND THE SELAWIK BASIN AREA

Alkaline intrusive rocks occur in a belt extending 225 miles from the Seward Peninsula and Kotzebue Sound eastward to Hughes on the Koyukuk River. Patton (1970, p. 1; 1973, p. A4) applied the name Hogatza Plutonic Belt to this feature. The belt is roughly 20 miles wide and lies principally in the western part of the Candle quadrangle and the southern parts of the Selawik, Shungnak, and Hughes quadrangles (fig. 27 and 28). This region is in the northern part of the Yukon-Koyukuk province, named after the principal rivers. The compositions of the plutons and the associated radioactivity anomalies make this one of the most interesting regions in the state for uranium-potential study.

The mountains and hills in the region are generally low and rounded and largely covered by soil and vegetation. Weathering has reduced most outcrops to rubble, and good exposures of the bedrock are scarce. Summits reach a maximum altitude of 3,300 feet in the Selawik Hills and 4,050 in the Zane Hills. Elsewhere the altitudes are less than 3,000 feet. The lowlands north of the plutonic belt are swampy, lake-dotted, and masked by alluvium and morainal deposits.

The region lies approximately on the boundary between the zones of continuous and discontinuous permafrost. The average annual temperature at Kotzebue is 20.7° F. The climate is arid; the average annual precipitation recorded for Kotzebue is 8.18 inches. Small, widely spaced settlements exist at Hughes, Hog River, Gabolio, and Selawik.

The region is relatively inaccessible and has been little prospected. However, geologic mapping, geochemical sampling, and radiometric surveys by the U.S. Geological Survey since about 1966 have revealed interesting possibilities for base metals and uranium in the intrusive rocks. Little is known about the sediments underlying the lowlands flanking the uplift or their potential for petroleum and uranium.

The Yukon-Koyukuk province as described by Patton (1973) includes two principal basins: the Kobuk-Koyukuk Basin in the northern part of the province and the lower Yukon Basin in the southern part. The basins are separated by the Hogatza Uplift, which contains the pluton belt--the feature of major interest with respect to uranium-potential investigations. The general stratigraphy of the region is briefly summarized and the possibility of sedimentary-type uranium deposition on the flanks of the uplift and in the nearby basins is considered. However, information on sediments in these areas is meager and the need for drilling to obtain subsurface data is acute.

The following descriptions of the sediments are taken from Patton (1973), who found that the earlier names and definitions applied to the units were too vague and generally unusable. There seems to be considerable overlapping of ages of the broad units discussed.

Sedimentary Rocks

Patton (1973, p. A2) described the northern part of the Yukon-Koyukuk province as a broad, wedge-shaped depression of Cretaceous and Cenozoic volcanogenic

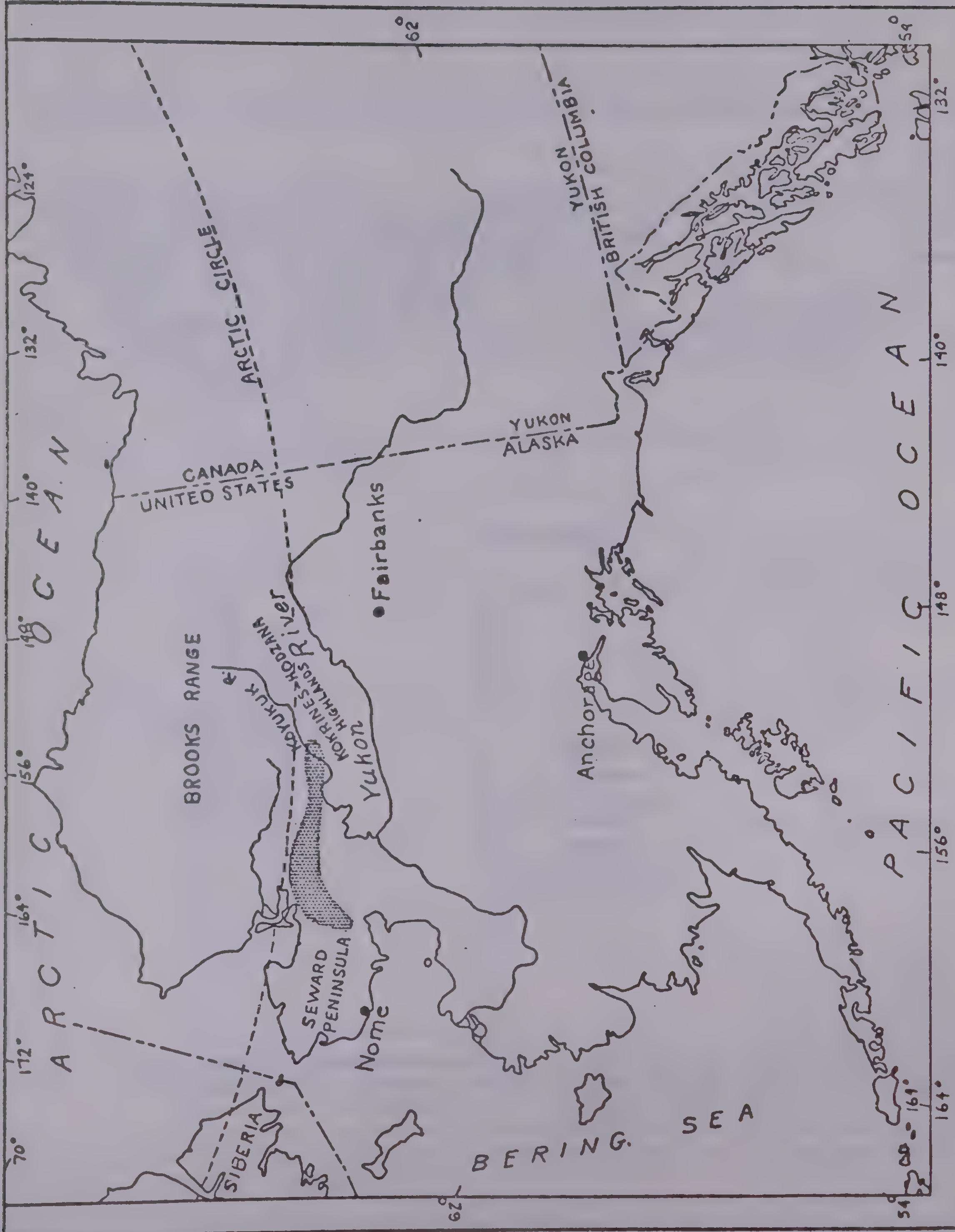


Figure 27. Location of Hogatza plutonic belt (shaded). (Source: Miller, 1970.)

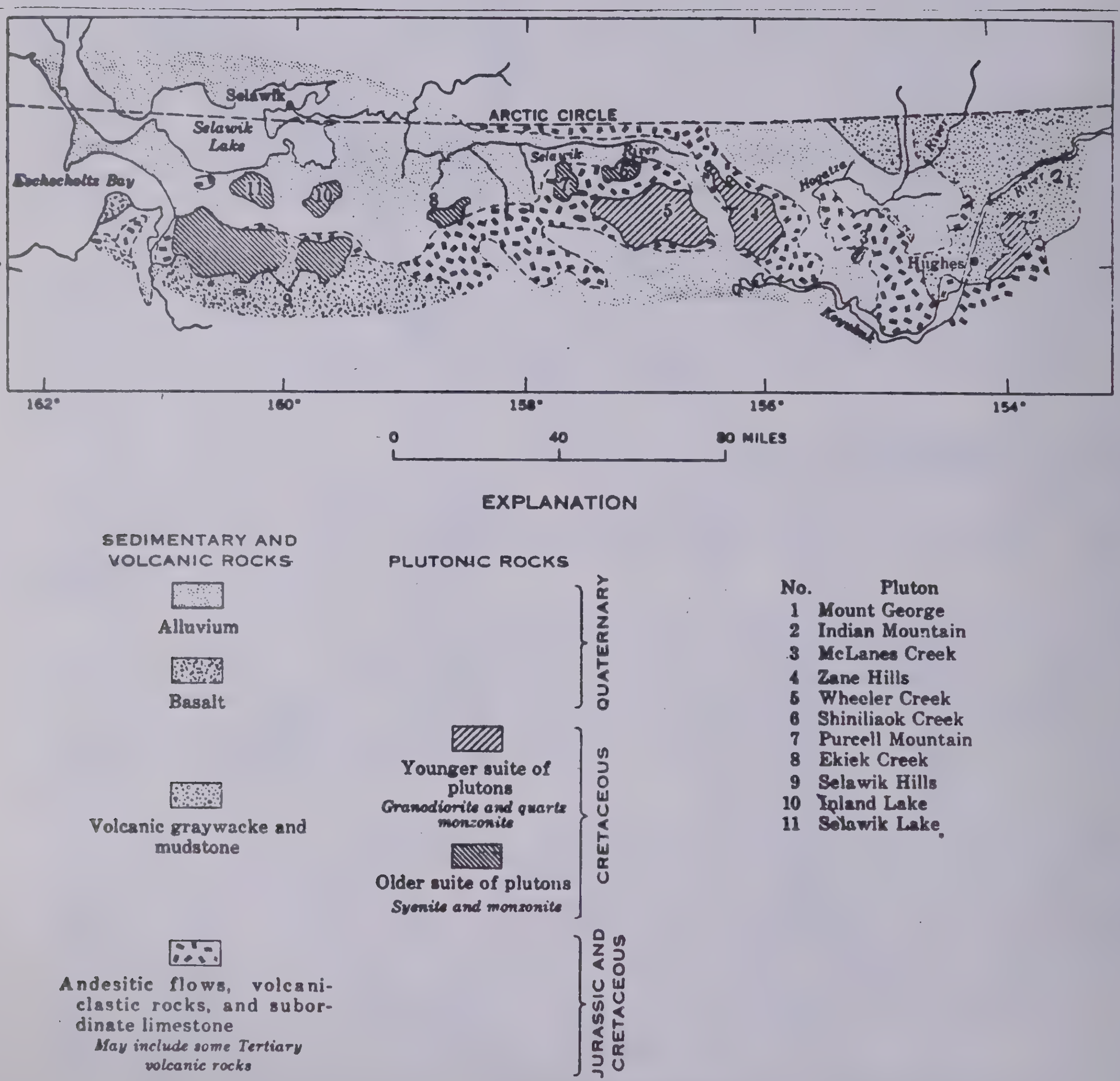


Figure 28. Generalized geologic map of west-central Alaska, showing location of plutons. (Source: Miller, Patton, and Lanphere, p. D159.)

rocks bordered on the north, west, and southeast by metamorphic rocks of Paleozoic and possibly older age (fig. 29). The triangular shape of this feature, with the open side to the west, is conspicious on the Tectonic Map of North America (King, 1969). This was a highly mobile region subjected to repeated episodes of volcanism and plutonism during Cretaceous and Tertiary times. Apparently the northern part was positive during most of the Paleozoic and early Mesozoic, and sediments of that area may not be present in the basins.

A narrow marginal band of rocks--Permian to Jurassic ophiolites--is present between the older rocks bordering the wedge and the interior of the province. The ophiolite is typically greenstone, but chert, pillow basalt, and serpentinite are present. Miller (1970, p. 2111) has suggested the possibility that this ophiolite underlying the Cretaceous rocks is oceanic crust.

Early reconnaissance geology and mapping in the region was done by Smith (1913) and Eakin (1916), but the following summary is based on the recent work by Miller and Patton between 1966 and 1973. Patton divided the sediments into three general sequences: (1) a Lower Cretaceous volcanic-mudstone sequence; (2) a younger sequence of Lower to Upper Cretaceous age, which was subdivided into four units; and (3) an Upper Cretaceous-Lower Tertiary sequence. Because of the poor exposures, the exact stratigraphic relationships of the three sequences is not clear.

The oldest rocks of the basin are Lower Cretaceous in age and consist mostly of volcanoclastics including lithic tuffs, breccias, conglomerates, and tuffaceous graywacke and mudstone which are believed to underlie the entire province (fig. 22). The thickness near Hughes is 5,000 feet, but the total may be several times this amount. Potassium-argon ages range from 134 ± 5 m.y. to 117 ± 4.3 m.y.

Lower and Upper Cretaceous rocks are present along the northern border and northeastern part of the province. These were referred to by earlier geologists as the Bergman Group (Schrader, 1904; Martin, 1926; Imlay and Reeside, 1954). Patton, however, abandoned the name and divided the sequence into four units:

(1) Volcanic graywacke and mudstone. In the northern part of the province, marine turbidites consisting of volcanic graywacke and mudstone up to 5,000 feet thick appear to have been derived partly from Late Paleozoic and early Mesozoic mafic volcanic borderlands. The sediments consist chiefly of volcanic rock fragments and feldspar with an argillaceous matrix. The graywacke and mudstone unit is widely distributed in the Hughes quadrangle where Patton and Miller (1966) stated that it contains an abundance of feldspar, some lithic tuff, and carbonized plant debris.

(2) Calcareous graywacke and mudstone. Possibly as much as 5,000 feet of shallow-water calcareous graywacke and mudstone overlie the volcanic graywacke and mudstone turbidites in the western part of the area. These strata were deposited in a relative small basin from the Kobuk River on the north to the middle of Selawik Lake on the south (fig. 28). The sediments coarsen westward, where they become conglomeratic and coal-bearing.

(3) Sandstone, siltstone, shale, and coal. Portions of this unit may be of interest to uranium potential studies, but its distribution is restricted to the lower Yukon-Koyukuk province.

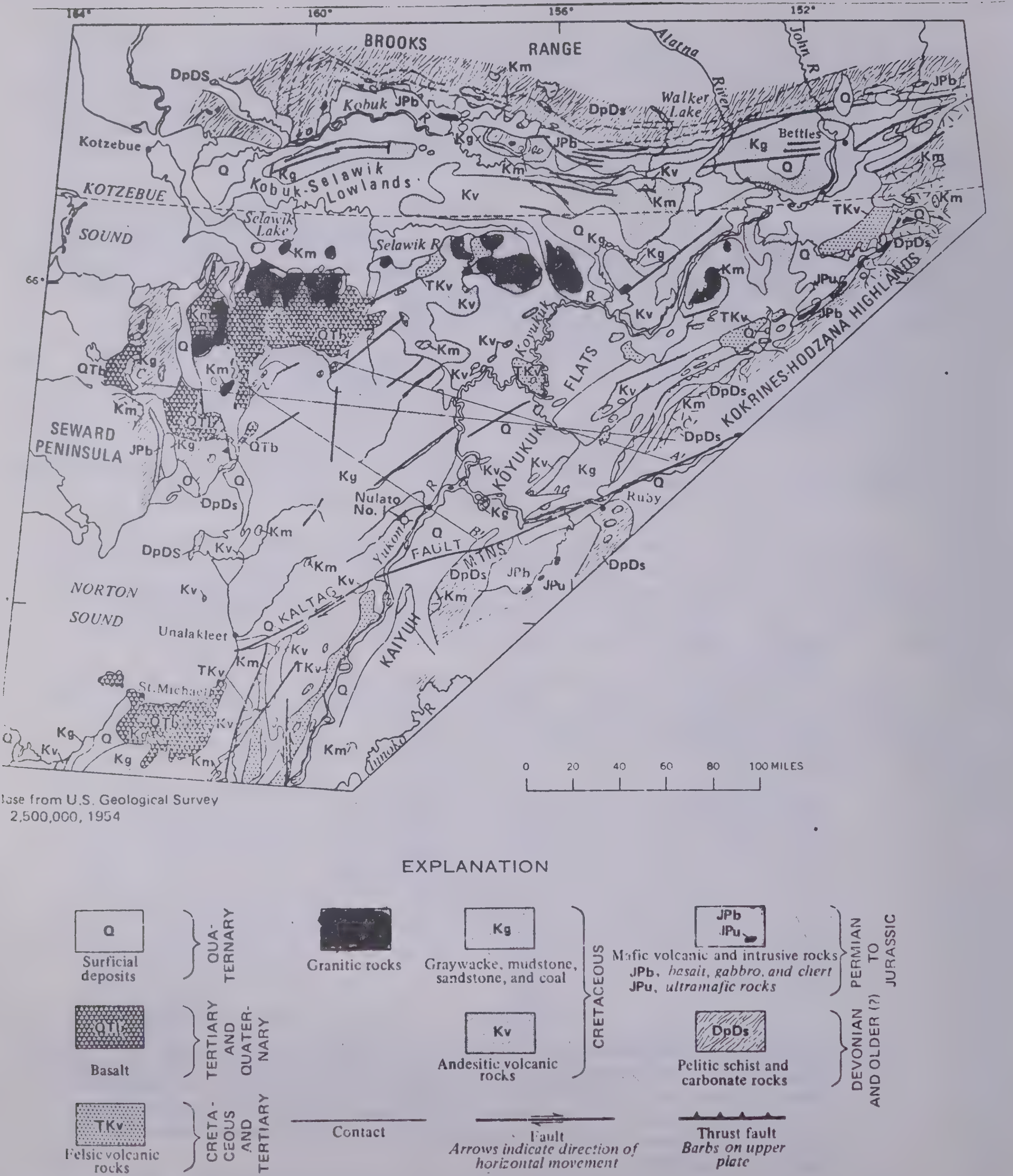


Figure 29. Reconnaissance geologic map of northern Yukon-Koyukuk province. (Source: Patton, Jr., 1973, p. A3.)

(4) *Marginal marine trough deposits. Nonmarine quartz conglomerate can be traced by scattered outcrops for about 450 miles along the northern and northeastern margins of the Yukon-Koyukuk province (fig. 30). The thickness was found to be 3,000 feet along the lower Kobuk River. The sediments appear to have been deposited in a narrow fault-bounded trench bordering the older metamorphic terrain. The unit is described as principally a quartz conglomerate, but it contains minor amounts of quartz sandstone, shale, thin bituminous coal beds, and ash-fall tuffs in the northern part of the Selawik quadrangle. The rocks in that quadrangle underlie four separate areas on the north side of the Waring Mountains and seem to have some favorable characteristics of sedimentary host rocks. The original distribution area, however, was probably small and suitable source rocks may have been scarce. The following description is from Patton and Miller's (1968) map of the Selawik quadrangle:*

Nonmarine conglomerate, sandstone, mudstone, and coal

Conglomerate composed chiefly of well-sorted white quartz pebbles in a quartzose and micaceous matrix; schist, chert, greenstone, and limestone pebbles in subordinate amounts. Light-gray to yellowish-orange, quartzose, calcareous, crossbedded sandstone (table 2, 66APa129) and dark carbonaceous and micaceous mudstone. Float of bituminous coal on Kobuk and south fork of Kallarichuk Rivers. Abundant well preserved plant fossils of probably Cretaceous age (personal communication, R.W. Brown, 1955; J.A. Wolfe, 1961, 1966). Potassium-argon age determination of 83.4±2.2 m.y. (Late Cretaceous) (table 1) from biotite from thin intercalated bed of ashfall tuff on Kobuk River. Unit poorly exposed except on Hotham Peak where it is estimated to be at least 3,000 feet thick.

The conglomerate unit to the east of the Selawik quadrangle is more metamorphosed, in part sheared, and less favorable as a possible host rock.

Upper Cretaceous and Lower Tertiary rocks include felsic extrusive and hypabyssal rocks. The flows are as much as 2,000 feet thick. The intrusives consist of swarms of dikes, sills, and plugs that cut the older Cretaceous volcanic and sedimentary rocks.

Poorly consolidated nonmarine coal-bearing beds of Tertiary age have been found at two localities in the northwestern part of the province. Sandstone and gravel are exposed in a 30-foot bluff on the Mangoak River in the Selawik Lowland (Patton and Miller, 1968); lignitic coal was found at the base of the bluff. A 2-foot seam of coal has been reported from a silt bluff near Elephant Point on Kotzebue Sound. Both deposits are probably confined to small structural and topographic basins or fault zones.

Petroleum companies have done limited work in the province in an effort to determine the petroleum possibilities. Subsurface data are not available from industry, but it is rumored that seismic surveys indicate several thousand feet of Tertiary and Mesozoic sediments with a good potential for oil are present in Kotzebue Sound. Standard Oil of California is preparing to drill three wells in the area in a joint venture with the Northwest Area Native Association, Inc.

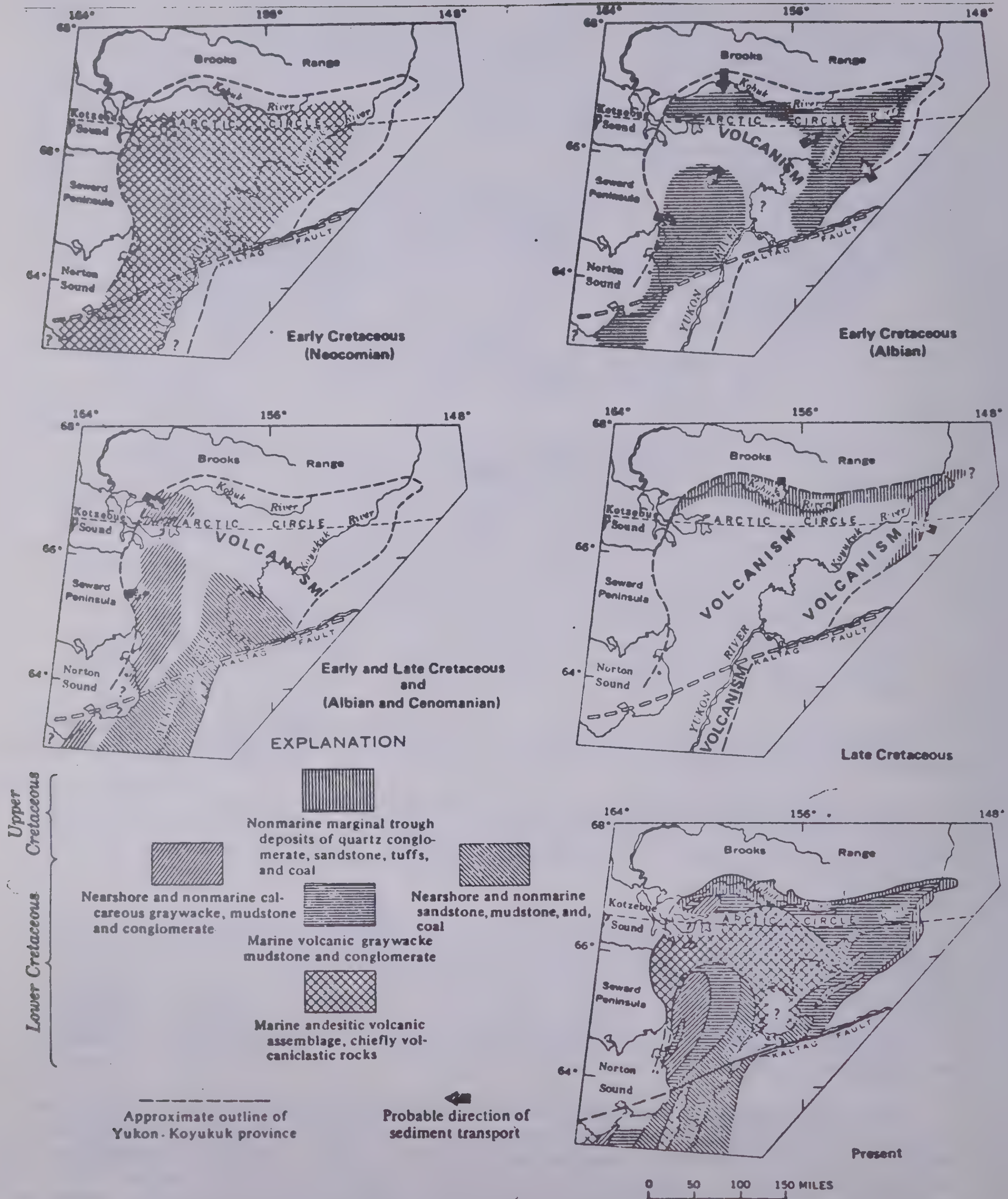


Figure 30. Cretaceous depositional basins and present-day distribution of major stratigraphic units in northern Yukon-Koyukuk province. Cretaceous depositional basins not palinspastically restored for offset along Kaltag Fault. (Source: Patton, Jr., 1973, p. A8.)

The unexplored Selawik Basin immediately north of the belt of alkalic plutons offers a setting warranting subsurface work to determine if possible uranium host rocks are present. The south flank of the pluton belt is covered by Tertiary and Quaternary volcanics and appears less likely to have suitable sediments.

The Pah River Flats is a 20- by 30-mile topographic depression bounded by the Lockwood Hills on the north, the Kokhila Hills on the east, and by the Babantaltlin Hills on the southeast. The hills are underlain by Cretaceous graywacke and mudstone and Jurassic and Cretaceous volcanics. The west and southwest edges of the depression are bordered by the Zane Hills pluton, which has yielded showings of copper, silver, gold, and molybdenum, and anomalous radioactivity. Border phases of the pluton near Caribou Mountain show radioactivity five to ten times the background radioactivity of the rest of the pluton, and 20 ppm uranium on analysis (Miller and Ferrians, 1968, p. 9).

The central part of the Pah River Flats is occupied by innumerable small lakes and muskeg. The saucer shape and poor drainage of this basin, which is adjacent to possible source rocks, suggest a favorable site for uranium concentration in sediments. However, available geologic maps of the area do not indicate the presence of a suitable host rock and drilling will be required to determine if any Late Cretaceous or Tertiary sandstones are present beneath the surficial deposits. The village of Hogatza, a few miles south of Pah River Flats, could serve as a base for exploration.

Plutonic Rocks

A 225-mile-long pluton belt extends from the eastern edge of the Seward Peninsula eastward to a point about 15 miles east of Hughes on the Koyukuk River (fig. 27). The belt trends east-west along the Hogatza uplift in the southern parts of the Selawik, Shungnak, and Hughes quadrangles, and trends north-south in the western half of the Candle quadrangle. The main part of the uplift borders the south side of the Selawik basin and the Pah River Flats.

Sixteen separate plutons that range in area from 3 to 350 square miles have been described and mapped (Miller, 1966, 1970; Patton, 1967; Patton and Miller, 1966, 1968; and Miller, Patton, and Lanphere, 1966). The largest (table 2) is the Selawik Hills pluton, which is 40 miles long and averages roughly 10 miles in width. The aggregate exposed area of the plutons is about 1,200 square miles. Portions are overlain by volcanic flows and welded tuffs of Late Cretaceous, Tertiary, or Quaternary ages so that the actual sizes of the plutons is greater than the outcroppings. The areas containing the plutonic rocks include Clem, Sugar Top, and Granite Mountains in the eastern part of the Seward Peninsula, and the Selawik Hills, Purcell Mountains, Zane Hills, Indian Mountains in the east-trending part.

Preliminary studies indicate the plutons are divisable into an older mid-Cretaceous (100-m.y.-old) suite in the western half of the belt, and a younger Late Cretaceous (81-m.y.-old) suite in the eastern half. Both suites intrude the thick earliest Cretaceous and possibly Jurassic sequence of marine andesitic volcanic rocks. The younger plutons also intrude mid-Cretaceous volcanic graywacke and mudstone in the eastern end of the belt.

TABLE 2. Sizes of the plutons in the Hogatza pluton belt, west-central Alaska

Name	Area ($mi.^2$)
Late Cretaceous Suite	
Zane Hills pluton	180
Wheeler Creek pluton	271
Indian Mountain pluton	85
Mt. George pluton	6
McLanes Creek pluton	8
Total	550
Mid-Cretaceous Suite	
Shiniliaok Creek pluton	30
Purcell Mountain pluton	40
Hawk River stock	5
Ekiek Creek Complex	5
Selawik Hills pluton	354
Hunt Complex	5
Inland Lake Complex	12
Selawik Lake Complex	7
Hunter Creek pluton	165
Granite Mountain pluton	27
Quartz Creek pluton	3
Total	653
Totals for both suites	1,203

The plutonic rocks have a wide range in composition in both the belt and in individual plutons. Rocks as potassic as those in western Alaska are relatively rare; many are unusual and do not fit into familiar classifications (Miller, 1970, p. 9). Rock types in the older suite are saturated to undersaturated and include pyroxene-hornblende syenite and monzonite, granodiorite, quartz monzonite, alkaline granite, nepheline syenite, and perthosite. In the younger, more silicic suite, the composition ranges from granodiorite to alaskite with minor amounts of monzonite and hybrid diorite; granodiorite is the most common rock type. Hornfels form narrow, resistant border zones adjacent to the plutons. Interesting mineral showings and geochemical anomalies are associated with the intrusives. Representative chemical analyses and forms of alkaline rocks from western Alaska are from Miller (1970):

REPRESENTATIVE CHEMICAL ANALYSES AND NORMS OF ALKALINE ROCKS FROM WESTERN ALASKA*

Sample No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Rapid rock chemical analyses (weight percent)†																		
SiO_2	44.5	46.1	48.9	50.3	50.7	51.4	52.2	52.4	54.1	55.4	55.8	57.2	57.8	58.1	54.8	56.5	60.0	56.4
Al_2O_3	11.0	15.0	12.1	15.0	17.8	12.2	15.2	19.9	17.2	21.6	15.2	21.4	22.1	22.0	15.6	19.4	17.4	19.0
Fe_2O_3	4.3	5.1	2.6	3.4	5.9	6.2	2.8	2.8	2.7	0.60	2.3	1.9	0.54	1.4	2.8	2.8	4.1	4.1
FeO	7.7	5.1	5.2	4.0	1.2	2.7	4.2	1.2	2.4	1.0	3.8	1.0	0.80	1.0	3.2	2.2	3.8	2.2
MgO	9.1	4.4	8.7	5.4	0.17	6.4	4.6	0.64	3.2	0.13	3.2	0.18	0.36	0.17	2.5	1.2	2.8	1.4
CaO	12.6	11.7	11.2	9.1	8.1	10.1	7.5	3.8	4.4	0.09	6.7	1.4	1.1	1.3	7.9	5.1	9.6	4.7
Na_2O	1.1	7.0	0.91	2.4	2.0	2.2	2.8	2.3	3.5	1.3	3.2	7.6	4.7	7.9	4.0	3.8	3.0	4.1
K_2O	4.4	3.4	6.1	6.3	11.3	5.0	7.3	10.3	7.2	16.6	7.0	8.1	9.4	5.8	5.8	7.4	5.9	6.4
H_2O-	0.29	0.27	0.49	0.24	0.19	0.30	0.19	0.04	0.68	0.12	0.26	0.80	0.39	0.11	0.04	0.21	0.19	0.20
H_2O+	1.5	1.0	1.4	1.6	1.1	1.1	1.2	3.3	3.1	0.80	1.0	0.66	2.4	1.2	0.75	1.5	1.6	1.5
TiO_2	2.0	0.38	1.6	1.2	1.2	1.2	1.2	1.1	0.71	0.28	0.96	0.29	0.27	0.22	1.4	0.62	0.90	0.59
P_2O_5	1.2	0.68	0.69	0.71	0.08	0.86	0.67	0.15	0.29	0.06	0.39	0.03	0.06	0.01	0.44	0.21	0.54	0.21
MnO	0.21	0.43	0.17	0.17	0.14	0.17	0.15	0.14	0.15	0.03	0.17	0.09	0.04	0.09	0.20	0.13	0.18	0.14
CO_2	<0.05	0.18	<0.05	<0.05	<0.05	<0.05	<0.05	0.36	0.08	0.21	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Total S as SO_3	0.00	0.34	<0.05	0.00	0.00	0.00	0.00	0.00	<0.05	--	0.00	0.00	0.00	--	<0.05	--	--	--
Sum	100	100	100	100	100	100	100	99	100	99	100	100	100	99	99	100	100	100
ZrO_2	0.05	0.03	0.04	0.10	0.20	0.04	0.04	0.05	0.09	--	0.07	0.11	0.02	--	0.06	--	--	--
Cl	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	--	0.00	0.01	0.00	--	0.00	--	--	--
F	0.34	0.11	0.33	0.25	0.40	0.20	0.18	0.12	0.15	--	0.20	0.40	0.06	--	0.57	--	--	--
BaO	0.44	0.06	0.72	0.27	0.13	0.38	0.29	1.25	0.17	--	0.18	0.01	0.13	--	1.12	--	--	--
CIPW norms (weight percent)																		
or	17.5	13.6	29.3	38.0	36.8	30.0	43.7	64.0	44.3	42.4	41.9	48.3	57.3	34.6	34.7	43.8	35.0	37.9
ab	--	--	--	5.8	--	17.6	6.9	3.5	22.5	--	19.7	21.4	23.0	38.7	24.2	20.6	7.0	29.0
an	12.3	0.7	11.1	11.8	6.3	8.8	7.5	14.3	10.4	2.7	6.5	0.4	5.2	6.4	7.6	14.0	16.7	14.6
lc	7.1	8.2	5.8	--	24.3	--	--	--	--	44.5	--	--	--	--	--	--	--	--
ne	5.1	31.3	4.2	8.1	9.3	0.8	9.3	9.2	4.5	6.0	4.2	23.6	9.8	15.5	5.5	6.3	10.0	3.2
wo	18.0	21.9	17.1	12.2	14.2	15.2	10.6	0.9	4.1	--	10.3	2.7	--	--	12.2	4.1	11.5	3.1
en	12.4	11.1	12.5	9.1	0.4	13.1	7.5	0.8	3.2	--	6.5	0.4	--	--	6.3	2.9	7.0	2.7
fs	4.2	5.4	2.9	1.9	--	--	2.4	--	0.5	--	3.1	--	--	--	1.6	0.9	2.4	--
fo	7.5	--	6.7	3.3	--	2.1	2.9	0.63	3.6	0.2	1.1	--	0.6	0.3	--	0.08	--	0.6
fa	2.8	--	1.7	0.8	--	--	1.0	--	0.6	0.7	0.6	--	0.2	0.4	--	0.03	--	--
mt	6.4	7.5	3.8	5.0	2.4	5.9	4.1	1.2	4.1	0.9	3.4	2.7	0.8	2.0	4.1	4.1	6.0	5.9
il	3.9	0.73	3.1	--	4.1	2.3	2.3	2.2	1.4	0.5	1.8	0.6	0.5	0.4	2.7	1.2	1.7	1.1
ap	2.9	1.63	1.7	2.3	2.1	2.1	1.6	0.4	0.7	0.1	0.9	0.7	0.1	--	1.1	0.5	1.3	0.5
cc	--	0.41	--	1.7	--	--	--	0.9	0.2	0.5	--	--	--	--	--	--	--	--

*Samples 1-13, Kobuk-Selawik Lowland: 1, biotite pyroxenite; 2, ijolite; 3-4, malignite; 5, borolanite; 6, shonkinite; 7, malignite; 8, borolanite; 9, trachyte porphyry; 10, juvite; 11, foyaite; 12, pulaskite; 13, juvite; 14, pulaskite.
Sample 15, Selawik Hills: foyaite dike.
Samples 16-18, Granite Mountain: 16, foyaite; 17, pseudoleucite porphyry; 18, garnet syenite.
†Analysts: Rapid rock analyses by P. Elmore, H. Smith, L. Artis, J. Glenn, S. Botts, G. Chloe, J. Kelsey; chemical analyses for ZrO_2, BaO, Cl, and F by J. Warr, Jr., P. Aruscavage, and J. Budinsky.

The alkaline nature of the plutonic rocks is discussed by Miller (1972, p. 2122):

> *The field and analytical data show that the alkaline rocks of western Alaska are epizonal plutonic rocks that are highly undersaturated in silica and rich in alkalis. Total alkali content ranges from a low of 5.5 percent in biotite pyroxenite to 17.9 percent in calsilite-bearing juvite. These are not peralkaline rocks--with one exception, the molar ratio of total alkalis to aluminum is less than one (Fig. 7).*
>
> *Many chemical characteristics of the alkaline rocks of western Alaska and Cape Dezhnev, while illustrating the alkaline nature of the rocks, are similar to those found in many alkaline-rock provinces. The western Alaska alkaline suite is unusual, however, in its high K_2O content and high K_2O/Na_2O ratio. K_2O is over 6 percent by weight in 14 out of 22 analyzed samples and is as high as 16.6 percent.*

The zoned complex at Granite Mountain is of particular interest. It is composed of four units: (1) a core of equigranular quartz monzonite, (2) an inner crescent-shaped zone of massive to prophyritic monzonite and quartzite monzonite,

and an outer crescent-shaped zone subdivided into (3) nepheline syenite and (4) garnet syenite. This magmatic segregation may possibly aid in concentrating uranium within one particular zone. The mineral deposits in the area and uranium occurrences are mentioned under Economic Geology.

The alkaline character, wide distribution, and reports of anomalous radioactivity of the plutons in the Hogatza pluton belt suggest a highly favorable region for uranium investigations, especially in light of the recent development of large uranium reserves in alaskite at the Rossing deposit in Southwest Africa. While the entire belt warrants careful study, the alaskite occurrences may be of particular interest, and a description of the Wheeler Creek pluton alaskite is quoted from Miller (1970, pp. 101 and 103):

> *Alaskite of the Wheeler Creek pluton.--Coarse-grained alaskite underlies the west end of the Wheeler Creek pluton (plate 3) and intrudes rocks ranging from Lower Cretaceous andesitic volcanics to the Upper Cretaceous dacitic hypabyssal rocks. Alaskite outcrops are characterized by rounded pink-colored hills with little vegetation and a mantle of grus. The alaskite itself is characterized megascopically by large (up to 1 cm) black smoky quartz anhedra in a setting of pink feldspar anhedra (fig. 27). The rock is characterisitically coarse-grained with an allotriomorphic granular texture. The abundance of the smoky quartz distinguishes this unit from the minor alaskite and aplite dikes that locally cut the Zane Hills pluton. The rock is generally a true alaskite, with less than 1 percent mafic minerals, although locally the mafic content reaches as much as 8 percent near the contact and in the alaskite dikes cutting the quartz monzonite-granodiorite to the east.*
>
> *The K-feldspar is typically "patch" perthite and generally forms subhedral grains (fig. 28). Plagioclase occurs as euhedra with weak normal zoning; the composition is* An_{8-10} *(albite-oligoclase). Quartz occurs as large anhedra with undulatory extinction. Biotite is the principal mafic mineral but hornblende is present locally near country rock contacts.*
>
> *A chemical analysis of alaskite is given in table 10 and shows the felsic nature of the rock. A striking difference between the norm and mode of the analyzed sample is the relative content of K-feldspar and plagioclase. (The norm shows more plagioclase and less K-feldspar than the mode.) The reason for this is probably solid solution of albite in K-feldspar; many alkali feldspar grains contain from a third to a half exsolved albite. On stained slab surfaces these alkali feldspar grains were counted as K-feldspar.*

Alaskite is present in other plutons in the Hogatza belt either as a major rock type or in dikes. The southern and western parts of the Selawik Hills pluton has been mapped as predominantly quartz monzonite and alaskite (Patton and Miller, 1968). The rest is largely syenite and monzonite. The composition, large size, and radioactivity anomalies of the Selawik Hills pluton make this an attractive area to explore for vein or Rossing-type uranium deposits. The presence of purple fluorite associated with pulaskite and perthosite in the alkaline complexes in the Selawik Lowlands (Miller, 1970, p. 46) may also be an indication of anomalous radioactivity. The possibility that this large pluton and others in the pluton belt have contributed significant amounts of uranium to concealed sediments in the lowlands warrants careful investigation.

Structure

The northern Yukon-Koyukuk province is in a highly mobile region that was subjected to repeated magmatism during Cretaceous and early Tertiary times. The Hogatza uplift extends from the Seward Peninsula and follows the east-west grain of the region. A major strike-slip fault, the Kaltag fault (which may have as much as 40 to 80 miles of right-lateral offset), transects the province between Unalakleet and Tanana (Patton and Hoare, 1968). The Kobuk fault (or trench) trends along the northern border of the province. Small faults are visible in most bedrock exposures. While the sedimentary rocks are moderately to strongly deformed they have not been regionally metamorphosed.

The Kobuk-Selawik Lowlands is a major feature of the region, but aeromagnetic profiles suggest that igneous rocks are at shallow depth and it seems unlikely that Cretaceous or Tertiary sedimentary rocks are very thick beneath the Quarternary surficial deposits. Compilation of gravity surveys in northwestern Alaska by D.F. Barnes of the U.S. Geological Survey shows a belt of gravity highs that extends through the Selawik Basin and militates "against the presence of the sedimentary basin postulated in preliminary petroleum investigations" (U.S. Geol. Survey, 1967, p. A91). Farther west, however, Cretaceous and younger sediments as much as 10,000 feet thick may underlie Kotzebue Sound (Patton, 1970, p. 1).

Economic Geology

Mineralization in the region is associated with the late Mesozoic plutons of the Hogatza pluton belt, especially on or near the contacts between the intrusive rocks and the country rock. A variety of base metals have been reported from lode prospects, placer workings, and geochemical surveys in certain areas of the pluton belt. The largest number have been found in the Granite Mountain area and in the Zane Hills. However, largely due to the remoteness of the northern Yukon-Koyukuk province, the plutons have remained underprospected.

Prospectors located placer gold in the Granite Mountain area in the early 1900's and in the Indian Mountains and Zane Hills in the 1890's. Most of the mining was sporadic and on a small scale, but a dredge was installed on Bear Creek on the east side of the Zane Hills at Hogatza in 1957, and accounted for a significant part of the gold production of the state through 1969.

Because certain mineral assemblages may be indicative of favorable environments for uranium, brief summaries of known mineralization are described below by areas. The areas will be mentioned in sequence, beginning at the southwestern end of the belt.

Granite Mountain Area

The mineralization at the Granite Mountain pluton offers strong encouragement to exploration for vein-type uranium deposits. The pluton is nearly circular and occupies about 30 square miles. It has been assigned a mid-Cretaceous age as a result of a lead-alpha age determination of 100±15 m.y. (Patton, 1967). It is the most southern intrusive in the group of plutons in the eastern Seward Peninsula. The nearest towns are Candle, 45 miles northwest; Buckland, 40 miles north; and Koyuk, 40 miles south. Fourteen lode deposits containing one or more minerals of lead, silver, gold, zinc, copper, or tungsten, and about 20 placer gold deposits

have been listed for the area (Cobb, 1972). Placer gold deposits have been worked on a small scale at several streams on the eastern and southern part of the mountain since the early 1900's. A little platinum was reported as a by-product. Description of new metaliferous deposits and stream-sediment analyses have been published by the U.S. Geological Survey (Miller and Elliott, 1969; and Elliott and Miller, 1969). Three areas were found to be of special interest, and the authors recommended for additional exploration: lead, zinc, and silver near Quartz Creek; molybdenum, bismuth, silver, copper, lead, and uranium deposits in the upper Peace River drainage; and a lead, zinc, and gold deposit at Bear Creek.

The Quartz Creek area contains numerous occurrences of argentiferous galena, sphalerite, pyrite, and arsenopyrite in an altered zone 18 miles long and 20 to 5 miles wide. The association of the sulphides with tourmaline is a striking feature. Stream-sediment samples yielded anomalous amounts of copper, antimony, and tin in addition to the metals already mentioned.

Anomalous concentrations of molybdenum, bismuth, gold, copper, and lead were found over a 2-square-mile area in the soils, stream sediments, and outcrops in the Peace River drainage basin. The metals are disseminated in a syenitic stock satellitic to the main Granite Mountain pluton. Pan concentrates collected during uranium investigations by the U.S. Geological Survey (Gault and others, 1953) showed anomalously high concentrations of uranothorianite and a variety of other minerals, including galena, chalcopyrite, bornite, tetrahedrite, sphalerite, pyrite, and pyrrhotite. Gummite was also observed in some mineral grains. The source of the uranothorianite was not located, but West (in Gault and others, 1953, p. 29-30) suggested the possibility of a lode at the head of Peace River.

North of the Granite Mountain pluton on Bear Creek, sulfides occur in quartz-calcite veinlets and as disseminated grains in andesite (Herreid, 1965). Placer gold has been mined along the creek sporadically for the past 60 years. Herreid (1965, p. 14) noted the presence of jasper and hematite at Bear Creek:

> *Many heavy red pebbles and irregular masses of this material in greenstone float were seen in the creek gravels. Some of this material has an iron content of about 50% and gives a red streak when scratched with a knife, indicating hematite.*

Moffit (1905, p. 64) also mentioned the presence of a heavy, cherty red material that clogged the sluice boxes of miners on Bear Creek. The presence of jasper and hematite are pointed out because they are sometimes associated with uranium deposits (Nininger, 1954, p. 27, 28, 48, 55). Analyses of rock samples from the andesite mineralized zone showed anomalous lead, zinc, silver, arsenic, cadmium, gold, copper, and antimony (Miller and Elliott, 1969, table 4).

Hunter Creek Pluton

The Hunter Creek pluton is north of the Granite Mountain pluton in eastern Seward Peninsula. It extends northward for 25 miles and includes Sugar Top and Clem Mountains. The pluton is mostly porphyritic monzonite and quartz monzonite. It occupies at least 165 square miles and is irregularly shaped. A small amount of placer gold from a few streams in the area has been the only mineral production. Geochemical stream-sediment sampling (Elliott and Miller, 1969, p. 6) produced 50 ppm tungsten and 300 ppm molybdenum from Hunter Creek near Sugar Top Mountain.

Beryllium was detected in four samples from streams in that area (10 to 15 ppm). Investigations for uranium (Gault and others, 1953, p. 24-27) found radioactive material in concentrates from the Connolly Creek-Hunter Creek area and near the head of West Clem Creek. Uranothorianite, gummite, and thorite were identified. A maximum eU of 0.16 percent was obtained from Muck Creek concentrates.

Selawik Hills Pluton

The Selawik Hills pluton extends 45 miles east-west and underlies most of the Selawik Hills south of the Selawik Lowland (fig. 30). It consists principally of monzonite and syenite and is exposed over an area of about 350 square miles. The only information on the economic geology is that provided by stream-sediment sampling (Elliott and Miller, 1969, p. 6):

> *Many of the samples (1-38) from several small streams on the north flank of the Selawik Hills have slightly anomalous concentrations of lead (18 samples with 70 ppm and 6 samples with 100 ppm); and one sample, locality 32, contained 300 ppm lead, 200 ppm zinc, and 3 ppm silver. At bedrock locality X, near sediment locality 32, minor amounts of disseminated galena, sphalerite, and pyrite were noted in quartz-calcite veins and in pink syenite. Composite grab samples of the sulfide-bearing rock contained up to 2 percent lead and up to 1 percent zinc, but the extent of the mineralized area could not be determined due to poor exposure.*
>
> *Beryllium was detected in concentrations of 10 and 15 ppm in four sediment samples (44, 45, 48, 51) from small streams on either side of the ridge south of Clem Mountain. One sediment sample (59) from Hunter Creek, just above the Left Fork, contained 50 ppm tungsten and 30 ppm molybdenum.*

Abnormal radioactivity of phonolite, fluorite-bearing nepheline syenite, syenite, and trachyte was reported in the Selawik Hills pluton (Miller, 1968, table 4). The high radioactivity of the rocks is probably due in part at least to the high K_2O content, which ranges from 4.8 to 8.4 percent and averages 6.2 percent (Miller, 1970, p. 28).

Kobuk-Selawik Lowlands Pluton

Two poorly exposed alkaline complexes crop out as low hills between the Selawik Hills and Selawik Lake (fig. 31). These are designated as the Selawik Lake and Inland Lake complexes (Miller and others, 1966, p. D159), and are 7 and 12 square miles in area, respectively. The complexes consist of a variety of unusual alkaline rock types. Chemical analyses of the rocks show that lead, strontium, lanthanum, and arsenic are relatively high (Miller, 1970, p. 57). Unusual amounts of fluorine and zirconium are also present: up to 0.57 percent F and 0.20 percent ZrO_6. The only information on the economic geology is derived from two stream-sediment samples from the west side of the Selawik Lake pluton. One sample produced slightly anomalous cobalt (50 ppm) and copper (70 ppm) (Elliott and Miller, 1969, p. 10). Anomalous radioactivity of the plutons was reported from an aerial radiometric survey (Miller and Anderson, 1969).

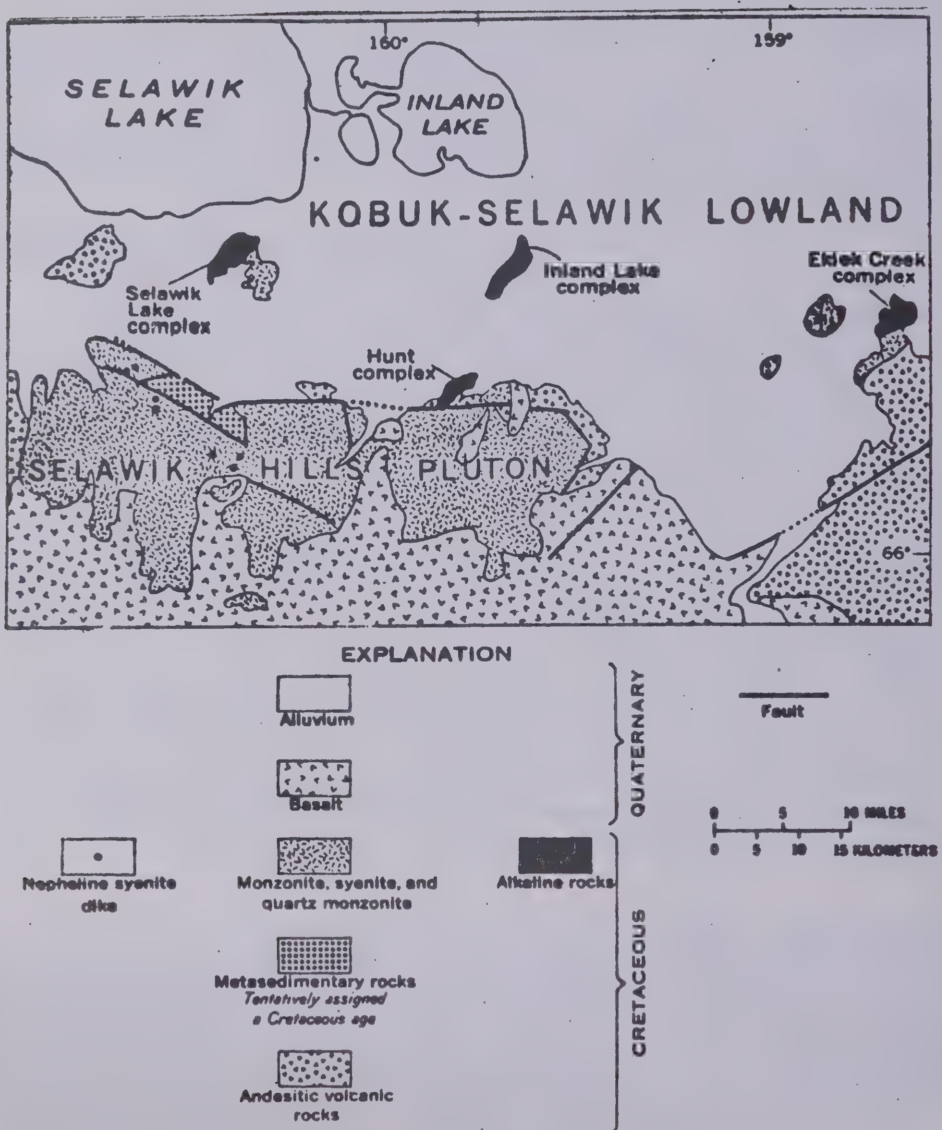


Figure 31. Generalized geologic map of the Kobuk-Selawik Lowland and Selawik Hills (after Patton and Miller, 1968). (Source: Miller, 1972.)

Ekiek Creek Complex

The Ekiek Creek pluton is a small intrusive, about 5 square miles in area, located about halfway between the Selawik Hills and the Purcell Mountains. It contains a wide variety of alkaline rocks. Two stream-sediment samples from the east side of the pluton did not show any anomalous metal values, but the aerial radiometric survey showed the northern end of the pluton to be anomalous (600 counts per second).

Shiniliaok Creek Pluton

The Shiniliaok Creek pluton occupies about 30 square miles in the north-central part of the Purcell Mountains. It is composed chiefly of medium-grained monzonite and syenodiorite. Tourmaline occurs as a widespread accessory and as massive veins in fault zones (Miller, 1970, p. 39). Little is available concerning the economic geology. A few widely spaced stream-sediment samples did not yield significant anomalies (Miller, 1969).

Zane Hills Pluton

The Zane Hills pluton is 180 square miles in area and forms a large part of the Zane Hills. The settlement of Hogatza (Hog River) is located on the east flank of the Zane Hills. The highest point in the area is Cone Mountain, 4,053 feet high. Granodiorite comprises about 90 percent of the pluton; monzonite and quartz monzonite compose most of the rest. Alaskite and aplite dikes are common. Placer gold mining was begun at Bear Creek, on the east side of the pluton, in the early 1900's. As stated earlier, a gold dredge was installed in 1957 and operated until 1969; it accounted for a substantial part of the state's gold production during that period. Unpublished reports indicate that cassiterite and platinum were also found in the Bear Creek placers. Bedrock and stream-sediment sampling (Miller and Ferrians, 1968, p. 6-10; Miller, 1969) revealed mineralization in the Zane Hills pluton at several locations. Massive pyrite is associated with silver and gold near the north end of the pluton. Zinc and molybdenum anomalies were also found nearby. Uphill from the Hogatza placer mine on Bear Creek, sediment samples were found to contain anomalous amounts of silver, bismuth, copper, and molybdenum. Two strongly anomalous areas of radioactivity were found in quartz monzonite: on the east side of Caribou Mountain and at the southern end of the pluton. The radiometric anomalies of these border phases were five to 10 times as high as readings over most of the pluton.

Purcell Mountain Pluton

The Purcell Mountain pluton is chiefly quartz monzonite and crops out over a 40-square-mile area in the Purcell Mountains. The only known mineral deposit is a gold placer mine on Shovel Creek on the northwest slope of Purcell Mountain. The mine was worked for about 10 years during the 1950's and 1960's, but the production is unknown. The gold may have been derived from quartz-tourmaline-sulfide veins near a contact between the quartz monzonite pluton and andesitic volcanics (Cobb, 1972, p. 35). An abundance of black tourmaline in the gravels was noted by Miller and Ferrians (1968, p. 11).

Hawk River Pluton

The Hawk River pluton, located 6 miles southeast of Purcell Mountain peak and about 2 miles southwest of the Wheeler Creek pluton, occupies 5 square miles. The small Hawk River stock consists of olivine-bearing monzonite cut by an east-west trending fault (Miller, 1970, p. 38). A quartz-rich zone 6-1/2 miles long by 1-1/2 miles wide trends northwest between the Hawk River, Purcell Mountain, and Wheeler Creek plutons. Grab samples from this zone contained anomalous values of copper, arsenic, lead, and zinc. Stream sediments indicated anomalous lead, copper, and silver (Miller and Ferrians, 1968, p. 10-11).

Wheeler Creek Pluton

The Wheeler Creek pluton underlies about 271 square miles of the Purcell Mountains. It is separated from the Zane Hills on the east by a 6-mile-wide valley. Most of the pluton is composed of porphyritic quartz monzonite and granodiorite. The west end of the pluton consists of coarse-grained alaskite which is characterized by smoky quartz. The alaskite body is about 36 square miles in outcrop area. Stream-sediment sample analyses did not reveal any mineralized areas (Miller, 1969), and no ore deposits are known.

Indian Mountain Pluton

The Indian Mountain pluton underlies about 80 square miles of the Indian Mountains and consists chiefly of hornblende-biotite granodiorite. Small amounts of zinc and copper sulfides, silver, antimony, gold, and lead have been found in the southeastern part of the hills near old placer-mine workings on Indian and Utopia Creeks. Some sulfide mineralization was found in boulders of barite (Miller and Ferrians, 1968, p. 3-6; Miller, 1969). Mineralization in additional areas is indicated by the presence of pyrite and conspicious gossans.

Radioactivity Investigations

Anomalous radioactivity has been reported from the plutons in west-central Alaska as a result of aerial and ground radiometric surveys, chemical analyses of the intrusive rocks, and testing of panned concentrates from stream gravels. High background counts can be expected over much of the pluton belt from the unusually high potassium content of the rocks; but uranium and thorium minerals have definitely been identified. Favorable mineral assemblages also are suggestive of possible vein-type uranium deposits.

An airborne radioactivity survey in conjunction with an aerial magnetometer survey covered 1,320 square miles of the southern Kobuk-Selawik Lowland (Miller and Anderson, 1969). The area covered extended from Kotzebue Sound eastward approximately 90 miles. The survey was flown and compiled by Lockwood, Kessler, and Bartlett, Inc., under a contract with the U.S. Geological Survey. The mean flight elevation was 400 feet above the ground. The plutons crossed during the survey were the northernmost tip of the Selawik Hills pluton, and the Selawik Lake, Inland Lake, and Ekiek plutons. The background over the lowlands and volcanic rocks was generally less than 100 cps (counts per second). The highest count (700 cps) was obtained over granitic rocks at the northern tip of the Selawik

Hills pluton. Counts of 500 cps were obtained over both the nephelene syenite of the Selawik Lake, Inland Lake, and Ekiek Creek plutons --- a figure five to 10 times higher than that of the surrounding terrain. Linear belts of high radioactivity (200 cps) north of the Selawik Hills pluton were jduged to be caused by concentrations of radioactive minerals in the gravels of streams draining from the Selawik Hills to the south.

Another aerial radioactivity survey was a single flight line made from near Kiwalik south of Kotzebue Sound eastward 80 miles, which covered the southern edge of the survey just described and traversed the northern part of the Selawik Hills. The survey was sponsored by the U.S. Geological Survey. The maximum count reported was 1600 cpm, registered over the northern tip of the Selawik Hills pluton. Other anomalies of 800 to 1000 cpm were obtained along with flight line. The background was between 300 and 400 cpm. Comments on the survey are quoted (U.S. Geological Survey, 1962, p. A52):

> *In evaluating previous aerial radiological measurement surveys, R.G. Bates obtained radioactivity values as high as 1,600 counts per second over stream gravels along streams draining to the north off the mountains south of Selawik Lake, Selawik quadrangle. These values indicate anomalous concentrations of radioactive minerals in the stream gravels and suggest that deposits of economic significance may exist within the drainage area.*

The exact position of the flight line is uncertain and the present writer questions whether the 1,600 cps was obtained over stream gravels rather than the pluton outcrop.

Ground investigations for radioactive materials were conducted in the eastern part of the Seward Peninsula by the U.S. Geological Survey in the late 1950's (Gault and others, 1953). Significant amounts of radioactive minerals were found on the southern slope of Granite Mountain in placer concentrates from Sweepstakes and Rube Creeks. Gault and others (1953, p. 1) described the findings:

> *A significant content of radioactive material was recognized in a few placer concentrates from Sweepstakes and Rube Creeks in the northeastern part of the Seward Peninsula, Alaska, when old collections were scanned for radioactivity in the spring of 1945.*
>
> *The later field investigations indicate that syenite is the only bedrock which has noticeable radioactivity, and stream concentrates that were radioactive were obtained only from creeks containing syenite in the gravels or flowing in areas underlain in part at least by the syenite. Crushed syenite samples from 14 localities show a content of radioactive material ranging from 0.001 to 0.013 percent equivalent uranium. The most radioactive unconcentrated material found is a 1-inch pegmatite dike cutting the syenite. The syenite stock is pre-Cretaceous and intrudes andesitic tuffs and flows that form the bedrock over much of the area.*
>
> *Two radioactive minerals have been recognized from the photographic effects obtained on alpha-ray plates, and are tentatively identified as uraninite-thorianite and hydrothorite. Almost all of the radioactive grains are uraninite-thorianite and only a few grains of hydrothorite were identified. Chemical analysis of a concentrate collected in 1917 from Sweepstakes Creek shows approximately equal amounts of uranium and thorium, and together they form more than 80 percent by weight of the sample. Chemical analyses of 5 of the samples collected in 1945 indicate a uranium content of 0.008 to 2.17 percent. In the sample which has 2.17 percent uranium, beta counts show 14.20 percent equivalent uranium and the difference is believed to be thorium.*

The occurrence of uranium and thorium in the headwaters of the Peace River on the southeast side of Granite Mountain has been described by West (1953, p. 28-31). Reconnaissance investigations for uranium during 1947 and 1952 revealed uranothorianite and gummite associated with copper sulfides, iron oxides, molybdenite, gold, silver, bismuth, and thorite in placers in a headwater tributary of the Peace River. Anomalous metal concentrations in stream sediments and outcrops occur over a 2-square mile area underlain by a small satellitic stock of the Granite Mountain pluton (Miller and Elliott, 1969, p. 12). The syenite locally contains purple fluorite. Concentrates from the placers contained between 0.2 and 0.8 percent eU, or about 10 times the eU of the average uranothorianite-bearing concentrates from other locations in the eastern part of the Seward Peninsula. The investigator of the Peace River locality concluded that the most probable source of the uranothorianite and gummite was a vein located in the rather restricted drainage area above the placer deposits. The evidence for a vein source is the sulfides associated with the uranium minerals and the lack of uranium minerals disseminated within the granitic rock itself. Although metallic lodes are known to occur in the general area, no uranium minerals were found in place.

Herreid (1965, p. 14) briefly visited the above mineralized area at the head of Peace River and obtained 350 ppm lead from a panned sample, and copper, lead, and molybdenum from stream sediments downstream. Heavy hematite staining of the creek gravels was reported.

After radioactive minerals had been found on the southern side of Granite Mountain, the U.S. Geological Survey continued investigations with a field study of the north side, in the headwaters of Quartz Creek (Killeen and White, 1953, p. 15-20):

> *The area to the north of Granite Mountain has even more uranothorianite (uraninite-thorianite of Gault, Black, and Lyons, 1946; and Frondel and Fleischer, 1959, p. 7) than the Sweepstakes Creek area and in addition carries uranium-bearing thorite(?).*

The gravels of Quartz Creek had formerly been mined for placer gold. The radiometric readings on the syenite bedrock was two to four times that of any of the surrounding rocks, and only the stream gravels derived from the syenite were radioactive. Tracing the radioactive gravels upstream, uranothorianite and thorite(?) were found in wash on the bank of a gulch in the headwaters of the south fork on Quartz Creek. The heavy fraction of two samples contained 0.06 and 0.088 percent eU (Killeen and White, 1953, p. 17). Concentrates from 21 stream gravel samples averaged 0.026 percent eU. Most of the radioactivity was attributed to uranothorianite and thorite, but radioactive zircon and sphene also contributed. The source of the uranium and thorium was thought to be either undiscovered veins or disseminations in the syenite of Granite Mountain.

Additional investigations of the Quartz Creek area (West and Matzko, 1953, p. 24) traced the occurrence of uranothorianite higher up the mountain slope than had been done in 1946. Concentrates ranging from 0.01 to 0.102 percent eU were obtained, and hydrothorite was found above the headwaters of Spring Creek.

North of the Granite Mountain area, parts of the Hunter Creek pluton were also investigated for radioactivity (West and Matzko, 1953, p. 21-27). The Hunter Creek pluton is part of the highland between the Buckland and Kiwalik Rivers and

has been called the Buckland-Kiwalik district. The Connolly-Hunter Creeks area, a few miles north of Quartz Creek, was sampled at 12 locations. Placer concentrates yielded eU values from 0.025 to 0.160 percent. The two highest values, 0.106 and 0.125 percent eU, were from Muck Creek concentrates. Uranothorianite was identified as some of the heavy fractions.

Still farther to the north at Clem Mountain, nine placer concentrate samples produced eU values from 0.027 to 0.106 percent. Uranothorianite was identified in three of the samples and thorite on one. Southeast of Clem Mountain, a sample from Sugar Loaf Creek produced a trace of orangite (similar to thorite) and thorite.

Anomalous radioactivity in the Selawik Hills pluton has already been mentioned in the discussion of aerial radiometric surveys in the region. Apparently, there have been no ground investigations for radioactivity similar to those in the Granite Mountain area, but Patton and Miller (1968, table 4) describe some of the rocks in the Selawik quadrangle as slightly radioactive phonolite, radioactive syenite, and radioactive trachyte. Radioactivity measurements were not given.

Two areas of the Zane Hills pluton near Caribou Mountain have been found to have strong radioactivity anomalies. These areas have been described and mapped by Miller and Ferrians (1968, p. 9-10):

> *Border phases of the Zane Hills pluton in two areas along the southeastern margin of the pluton (fig. 3, map unit kmq) show anomalous radioactivity-five to ten times the background radioactivity of the rest of the pluton. These border phases are composed of medium- to coarse-grained, trachytoid to gneissic, hornblende-biotite quartz monzonite and monzonite readily distinguishable in the field from the typical massive, granitic-textured granodiorite of the rest of the pluton.*
>
> *An analysis of porphyritic quartz monzonite from this border phase shows 20 ppm of uranium. This is five to six times more than the published averages for rocks of this composition (Smith, 1963, p. 402). Examination of thin sections of this rock shows that biotite and hornblende contain numerous inclusions surrounded by pleochroic halos indicative of radioactivity. Some of these halos are obviously around zircon crystals, but other much more intense halos are around grains of a colorless to faintly yellow, isotropic mineral of high relief. A thin section of this porphyritic quartz monzonite was exposed to a thermal neutron beam in a reactor in order to cause the fission of* U^{235}. *The fission events were recorded in a piece of lexan which covered the section. Later, etching of the lexan showed the anomalously occurring uranium in the sample to be associated with the colorless isotropic mineral.*
>
> *Although the uranium-bearing mineral is only a minor constituent in the samples studied, it may be more abundant elsewhere in the radioactive border phase-possibly in amounts large enough to be important economically, or other uranium minerals may be present. A panned concentrate collected in 1964 from Caribou Creek on the southeastern side of the Zane Hills contained 200 ppm of thorium, which was probably derived from this more radioactive border phase of the pluton.*

Three areas outside the pluton belt and Selawik Basin region, but marginal to them, have been checked for radioactivity. They are Cretaceous sediments near Kiana on the Kobuk River and the copper deposits in the Cosmos Hills on the south side of the Brooks Range. During a survey for radioactivity along the Kobuk River

(Matzko and Freeman, 1963, p. 38), Cretaceous quartz conglomerate, sandstone, carbonaceous sandstone, shale, and minor amounts of coal and altered tuff were examined. A slight increase in radioactivity was noted in the carbonaceous shale and sandstone.

A copper deposit 12 miles north of Shungnak village on Ruby Creek in the Cosmos Hills was found to contain anomalous radioactivity (Matzko and Freeman, 1963, p. 39-40; Runnels, 1964, p. 69, 78; Saunders, 1952, 1955, 1956, 1962). The camp where the mine is being developed by Kennecott Mining Company is called Bornite. The ore contains chalcopyrite, bornite, galena, sphalerite, silver, cobalt, and pyrite as replacements in a brecciated Devonian limestone or dolomite. Purple fluorite has also been reported. The most radioactive parts of the veins gave readings up to 0.30 mr/hr, and one sample from a core assayed 0.275 percent eU. An earlier report on the Ruby Creek copper deposit was made by White (1950), who quoted the following results from the U.S. Geological Survey laboratory:

> *Fluorimetric observations indicate that uranium is present in sphalerite, secondary hematite associated with limonite, and in copper carbonate stains. The sphalerite occurs as veins closely associated with pyrite and the hematite associated with limonite as crusts along fractures.*
>
> *A fluorimetric uranium determination......shows that the sphalerite contains .013 percent uranium. The sample submitted for determination was not entirely free from pyrite and gangue material.*
>
> *Radiometric determinations....gave the iron fracture zone a reading of .013 percent equivalent uranium and a representative fraction of the sample a reading of .007 percent equivalent uranium.*

Much drilling has been done on the property and a 1500-foot shaft sunk, but no further information concerning uranium in the ore has been published, and it is probably present only in minor amounts. The copper reserves are very large.

During the 1974 field season, while mapping in the western Brooks Range, the Alaska Division of Geological Survey discovered a highly radioactive locality. A large north-trending dike of fluorite-bearing nephlene syenite exposed on the north side of the Kobuk River, 15 miles east of Kiana, produced 600 cpm on the ground. The background was 40 cpm. A hand sample of the dike assayed 17 ppm. Nearby granite produced counts of two and a half times that of the background.

Discussion

The highly alkaline pluton belt in west-central Alaska is known to be anomalously radioactive in several areas. The wide extent of the plutons, combined with the presence of uranium and thorium minerals positively identified in placer concentrates in the Granite Mountain, Clem Mountain, and Zane Hills areas, make this province highly attractive for uranium exploration---possibly the best region in the state. The entire pluton belt in west-central Alaska and the nearby lowlands warrant detailed investigations to determine the potential for vein-type deposits. Most of the region is remote, and logistic problems will be severe. Bedrock exposures are poor in parts of the region and it may be necessary to use a variety of techniques to locate and evaluate all the radioactive anomalies. The presence of alaskite over a considerable portion of the plutons and favorable mineral assemblages found in stream-sediment samples and outcrops are added encouragements.

Little information is available on the sediments in the lowlands near the plutons, and work is critically needed to determine if sediments are present that could be hosts for uranium deposits, especially along the south side of the Kobuk-Selawik Lowland, the Pah River lowland, and the slopes of the mountainous areas underlain by alkaline plutons. Parts of the Cretaceous conglomerate in the Selawik quadrangle and graywacke-mudstone unit in the Hughes quadrangle are nonmarine, tuffaceous, and carbonaceous and should be examined. Much of the pluton belt and lowland areas are still unexplored. Instruments more sensitive than those used by earlier investigators should permit more revealing surveys.

THE SEWARD PENINSULA

The Seward Peninsula in west-central Alaska between Kotzebue Sound on the north and Norton Sound on the south is approximately 200 miles long by 150 miles wide and includes 37,000 square miles. The westernmost tip, Cape Prince of Wales, extends into the Bering Strait to within 50 miles of the USSR mainland. The Seward Peninsula is a part of the interior uplands. It does, however, contain small interior basins and coastal lowlands separated by isolated groups of rugged mountains with peaks between 2,500 and 4,700 feet high. The interior basins are drained by narrow canyons cutting the intervening highlands. Most of the region, however, is occupied by low, rounded hills under 2,000 feet.

The Seward Peninsula is one of the most highly mineralized regions in Alaska and must be considered a possible source of radioactive materials. As of 1961, the peninsula had produced 30.7 percent (6,260,000 fine ounces) of the placer gold produced in the entire state (Cobb, 1972, p. 37). The famous beach placers and nearby streams in the Nome area, discovered in 1898, are thought to have produced 75 to 80 percent of the peninsula's gold. A small amount of platinum was produced as a by-product. Lode deposits have been less important, but they are widespread and have either produced or been found to contain significant amounts of tin ($3,000,000+), tungsten, antimony, beryllium, and gold. Small amounts of bismuth, copper, lead, iron and mercury have been found but not produced. Anomalous radioactivity has been found in several areas. In addition to the known mineralization and the presence of small basins, the Seward Peninsula is of interest from the standpoint of uranium exploration because it is one of the few regions in Alaska where Precambrian rocks are definitely known.

The climate is characterized by cool summers and very cold winters. All the peninsula north of the Kigulaik Mountains is within the permafrost zone. For the most part it is a treeless, windswept, tundra-covered region with a sparse population. Most of the inhabitants live in Nome, which has a population of about 2,500.

While mining on the peninsula has been largely dormant for many years, the recent increase in the price of gold has caused some activity. Two or three dredges have been reactivated in the Nome area. The major development in recent years has been by the Lost River Mining Corporation, which is preparing a large-scale operation to mine the fluorite-tin-tungsten deposits at Lost River on the southwest side of the York Mountains. The fluorite reserves may be the largest in the world.

The geology of the Seward Peninsula is varied and highly complex. Sedimentary and igneous rocks represent most of the geologic ages from Precambrian to Quaternary. The numerous mineral occurrences have resulted in the publication of many reports on the economic geology and mining properties, but the regional structure and

stratigraphy are still being unraveled. Much of the Precambrian and Paleozoic terrain is believed to be more closely related to that of Siberia than to the rest of Alaska.

Following many seasons of geologic mapping on the Seward Peninsula, Sainsbury (1969, p. 2595) concluded that the rocks on the entire peninsula are involved in imbricate thrust sheets and that recognition of the thrusting has forced the complete revision of the assigned ages and groupings of all the rock units. He added that all ideas as to structure and stratigraphic relations published before 1965 are in error, insofar as rocks of pre-Jurassic age are concerned. Some rock units remain unassigned to any age.

A general statement on the geology of the Seward Peninsula is taken from Sainsbury and others (1970, p. 2502):

> *The Seward Peninsula consists principally of metamorphic rocks of Precambrian age, of less metamorphosed pelitic and carbonate rocks of late Precambrian age, and of thick carbonate rocks of Paleozoic age. These rocks are intermixed in extensive thrust plates of two ages: the earlier (eastward thrusting) is probably pre-middle Cretaceous, and the later (northward thrusting) is older than 74 m.y. Stocks and batholiths of granitic rocks, containing alkalic rocks locally, and gneissic phases intruded the older thrust plates, whereas stocks of biotite granite with associated tin and beryllium deposits intruded the younger thrust sheets. Extensive andesitic volcanic rocks on the eastern Seward Peninsula are of Late Jurassic to Early Cretaceous age; they grade upward into graywackes and siltstones of Cretaceous age which are tightly folded. Tertiary rocks are coal-bearing and deformed and crop out in small areas; they are most probably of late Tertiary age. Extensive volcanic fields of latest Tertiary to Holocene age cover large areas of the central and eastern Seward Peninsula. Marine terraces older than Sangamon are warped, and a range-front fault along the Kigluaik Mountains offsets moraines of Wisconsin age.*

The geology and mineral deposits of the Seward Peninsula suggest that the greatest probability of uranium concentrations would be in veins; therefore the principal mineral occurrences and reports of anomalous radioactivity are summarized. Mineral assemblages considered to be favorable for uranium association are present. However, the principal lowlands and interior basins are indicated on the accompanying 1:1,000,000 scale map, and insofar as possible, their favorability as uranium host rocks is evaluated.

Stratigraphy

Some of the problems of attempting to summarize the stratigraphy of the Seward Peninsula were mentioned in the introductory statements. The bedrock of most of the Seward Peninsula, including the Kigluaik, Bendeleben, and Darby Mountains, is chiefly Precambrian and Paleozoic schist, gneiss, marble, and metamorphic volcanics, all of which have been intruded by granitic rocks. The York Mountains in west-central Seward Peninsula consist of a mass of resistant marble. A lava plateau of Quaternary age occupies a large area in the north-central part of the peninsula.

The Precambrian rocks of the Seward Peninsula are believed by Sainsbury and others (1972, p. 2-7) and Sainsbury (1974, p. 4-9) to belong to two units: the York Slate and a schistose argillaceous carbonate unit. The term 'York Slate' was proposed to largely replace the Kigluaik Group, Nome Group, and other formation names previously regarded as Precambrian in age. The Kigluaik Group, the Tigaraha Schist, and the Nome Group all contain rocks of the York Slate, or their metamorphic equivalents. Thirteen Rb-Sr analyses of whole rock samples indicate an age of 700 m.y. for the regional high-grade metamorphism of the Precambrian rocks (Sainsbury and others, 1970, p. 2502-2503).

The York Slate underlies most of the Seward Peninsula, though its stratigraphy is very confusing because of the diverse lithology, varying degrees of metamorphism, and widespread thrust faulting. Included within the York Slate are many lithologic types, ranging from a dark siliceous phyllite containing as much as 92 percent SiO_2 through highly calcareous, graphitic, or carbonaceous phyllite, to mixed siliceous schists containing large amounts of either chlorite or graphite, or both. Siliceous carbonaceous quartz siltite forms the bulk of the unit. Marble and schist beds are common in the upper part. Large exposures of chloritic or feldspathic schist and semischist, which probably represent intercalated volcanic or volcanoclastic rocks, are present on the Seward Peninsula, but Sainsbury (1974, p. 9) considers the many gabbroic and metagabbroic bodies that have intruded the York Slate as Precambrian. As unmistakable relationship between placer gold in the Bendeleben quadrangle and the distribution of the York Slate was noted by Sainsbury (1974, p. 5), for practically no placers are found outside the slate areas.

A schistose, argillaceous, and dolomitic limestone-and-marble unit is transitional above the York Slate and contains numerous quartz carbonate veinlets. Thin (up to 1 inch) beds of silty claystone are interlayered with beds of fine-grained, silty, argillaceous, and dolomitic limestones. This unit is assigned a late Precambrian age because of a complete lack of fossils and because it is transitional with the York Slate. This unit is exposed in the York Mountains, in the Solomon D-6 quandrangle, and in the southeastern part of the Seward Peninsula.

Generalized descriptions of the Paleozoic and Mesozoic rocks of the Seward Peninsula are drawn from Churkin (1973), Sainsbury (1969, 1974), Sainsbury and others (1972), Smith and Eakin (1911), and Steidman and Cathcart (1922). The stratigraphy of the central York Mountains summarized on page 114 shows the general lithologies and thicknesses. The Paleozoic sedimentary rocks consist predominantly of thick carbonate units with minor interbedded schist and shale beds. These have been highly deformed, recrystallized, and thrust faulted. Total thicknesses of the units are not known, but they are probably in the thousands of feet. Exact ages and correlations between different areas are often uncertain.

An argillaceous and dolomitic limestone of Cambrian(?) age underlies the Ordivician Port Clarence limestone on the westernmost tip of the peninsula. Minute cubes of pyrite are locally abundant and produce an orange-red coloration in outcrop (Sainsbury, 1969, p. 9). Some units contain silty terrigenous material.

Thin-bedded to massive argillaceous and dolomitic limestones of Ordivician and Silurian ages form the bulk of the York Mountains and crop out in the Teller quadrangle, 80 miles to the east. These rocks contain thin black shales and terrigeneous material. They are at least 8,000 feet thick.

Stratigraphic column of rocks exposed in the central York Mountains, western Seward Peninsula. (Source: Sainsbury, 1968.)

Age	Unit	Thickness (feet)	Description
Quaternary	Qal	Variable	Includes alluvium, terrace gravels, glacial moraines, outwash gravel, talus cones and beach deposits, all of which occur on all geomorphic units older than Recent in age
	Qpc	10-110	Conglomerate on the York terrace, lower part of marine origin, upper part of continental origin
			UNCONFORMITY
Late Cretaceous to early Tertiary	TKd	Dikes and plugs	Dikes, including lamprophyre, diabase, rhyolite, quartz-porphyry and andesite
	TKg	Stocks	Medium- to coarse-grained biotite granite
Early to Middle Ordovician	Odl	At least 1250	Principally medium-gray to dark-gray, medium-bedded fossiliferous limestone
			FAULT
	Oshl	At least 2400	At base, black shale and siltstone; grades upward to black, sugary-textured limestone, and thence to medium-gray to dark-gray limestone, largely dolomitized
	Ol	Probably 6500	Massive to thick-bedded micritic limestone containing chert nodules locally, and subordinate interbeds of thin-bedded, argillaceous limestone
	Oal	Possibly 4500	Thin-bedded argillaceous and silty limestone, dolomitic limestone and carbonaceous limestone, with subordinate interbeds of massive limestone
			FAULT
pre-Ordovician	pOg	Plugs, sills, dikes	Medium- to coarse-grained gabbro
	pOal	Several hundred	Thin-bedded argillaceous and dolomitic limestone, silty limestone, and shaly limestone that contains numerous veins and veinlets of quartz and carbonate
	pOs	Undetermined	Includes slate, phyllite, slaty limestone, siltstone, graywacke, and minor argillaceous limestone, all moderately to intensely deformed.

Devonian rocks are present in large portions of the central and eastern Seward Peninsula. They include white massive crystalline limestone with thin dolomite interbeds. Some dark shale and black limestone are present in the Darby and Bendeleben Mountains.

No rocks of Pennsylvanian age are known on the Seward Peninsula. Miller and others (1972) reported Permian metavolcanic rocks largely altered to glaucophane schist along the Kugruk and Koyuk Rivers. Sainsbury (1974, p. 10), however, assigned these rocks to the Jurassic period.

During Mesozoic time, the Seward Peninsula, as a part of the Chukotskiy-Seward uplift, was mostly emergent (Payne, 1955). The peninsula underwent uplift and strong deformation and was a source of the sediments in the Koyukuk geosyncline to the east and southeast.

Triassic sediments are not known on the peninsula. Basic intrusives and extrusives were emplaced during the Jurassic period, and widespread intrusions of granitic bodies and mineralization accompanied the deformation during mid-Cretaceous time. Sedimentary rocks of Mesozoic age include only a few small scattered deposits of conglomerate with minor amounts of shale and coal.

A small area, possibly 3/4 of a square mile, of coal-bearing Cretaceous rocks are poorly exposed in a gulch that is a tributary to the Sinuk River, 13 miles from the coast. The rocks are principally conglomerate and contain pebbles of schist and vein quartz, and several coal beds from 3 to 16 inches thick (Collier and others, 1908, p. 84). The beds have been crushed and sheared. Another small exposure of Cretaceous cobble conglomerate with clasts of limestone, greenstone, and schist has been mapped north of the Bendeleben Mountains near the head of Knowles Creek (Miller and others, 1972). The unit includes minor beds of graywacke and thin coal seams.

Sainsbury (1974) mapped a discontinuous series of probable Cretaceous sediments in a belt along the east front of the Darby Mountains and northward along the Kugruk River. The largest exposure is in the extreme southeastern corner of the Bendeleben quadrangle. It is approximately 1/2 mile wide and 4 miles long and at least 200 feet thick. The unit is named the Spruce Creek formation (Sainsbury, 1974, p. 11). It consists of a cobble conglomerate with clasts of limestone and dolomite with subordinate volcanic rocks, chloritic schist, and York Slate.

In the early 1900's, coal of late Cretaceous or early Tertiary age was mined to at least three separate underground mines along the Kugruk River. The coal-bearing beds crop out along the river at points between 12 and 22 miles from the coast on Kotzebue Sound (Sainsbury, 1974). There is no complete description of the section, but the following observations were made by Moffit (1905, p. 25):

> *Sandy and shaly sediments interbedded with thin limestones were noticed at several localities in the valley of Kugruk River, especially in the vicinity of Chicago Creek, where they are associated with deposits of lignitic coal. These beds are folded and much jointed, but have not been altered to the same degree as have the neighboring schists. They have the same north-south strike and high dips common in the highly metamorphic rocks,.and, when weathered, their altered surfaces present an appearance very similar to that which would have resulted had they been burned. Such outcrops were noticed on Kugruk River near the mouth of Chicago Creek one-half mile above the Kugruk.*

Henshaw (1909, p. 362-363) and Reed (1933) reported on the coal mines. Three mines had inclined shafts that were between 144 and 330 feet long and reached depths of 200 feet below the surface. The coal seam averages an amazing 85 feet in thickness and contains only a few interbeds of shale and fire clay, all less than 1 foot thick. The seam strikes N 9° W and dips 50° to 70° W. The coal is lignitic but burns well.

Erosion has removed some of the Cretaceous sediments, but the remaining deposits do not suggest that they were ever extensive. Although there is no evidence that they are present beneath the Quaternary cover in the lowlands, it is a possibility. At least some of the Cretaceous sediments on the Seward Peninsula are described as nonmarine and seem worthy of study for sedimentary uranium deposits.

During most of Tertiary time the Seward Peninsula must have been on a highland that extended across the Bering-Chukchi marine platform and was eroded to a low,

undulating surface (Hopkins, 1963, p. C27). Continued faulting and warping have resulted in deformation of sediments as young as Pleistocene. Exposures of Tertiary sediments seem to be even more limited than those of Cretaceous age.

The most extensive Tertiary beds known on the peninsula may underlie the Quaternary cover in the upper Kuzitrin River lowland in the central part of the Seward Peninsula. Sainsbury (1974) called the lowland a Tertiary basin. The basin occupies roughly 300 square miles; the northeastern end is covered by Tertiary or Quaternary basaltic flows. A description of this feature is quoted from Sainsbury (1974, p. 12):

> *Rocks of unquestionable Tertiary age in the Bendeleben quadrangle are found only in the small Tertiary basin traversed by the Noxapaga and Kuzitrin Rivers in the west part. Although Hopkins (1963), who named the rocks in the Kougarok Gravels, included both unconsolidated gravels and the underlying coal-bearing beds in the same unit, I have assigned two different names. The Lower conglomerates, sandstones, thin coal and fireclays are renamed the Noxapaga Formation, whereas the designation Kougarok Gravels is retained for the younger gravels which I assign to the Pleistocene. The Kougarok Gravels display abundant fossil ice-wedge casts, are unconsolidated, and are unquestionably of Pleistocene age.*
>
> *The Noxapaga Formation is exposed only in trenched pingos west of the Noxapaga River, where lignitic coals are bowed up to the surface in large pingos, as well as along the cutbanks of Turner Creek, where squirrels have thrown the coals up in borrows. Hopkins (personal communication, 1973) states that sandstones are locally present along Dahl Creek.*
>
> *A deep shaft on Turner Creek (Hopkins, 1963, p. C30), penetrated sandstone, lignitic coal, fireclay and weakly lithified conglomerate. All these rocks are assigned to the Noxapaga Formation, so that the more descriptive term Kougarok Gravels may be correctly applied to the overlying unconsolidated gravels.*

The following generalized description of the stratigraphy of the Teritary unit and overlying sediments in the above area was compiled by Hopkins (1963, p. C30):

Thickness (feet)	*Lithology*	*Present Interpretation*
15-20	*Frozen organic silt and peat.*	*Windblown silt and colluvium of late Quaternary age.*
3-15	*Fine reddish gravel and sand, lenses of silt and fresh-looking wood; locally gold-bearing at base.*	*Upper member of Kougarok gravel; of late Tertiary or early Quaternary age.*
0.5-2.0	*Sticky blue-gray clay or muck; a spruce log, 80 ft. long and 5 ft. in diameter, and an associated horse jaw found in frozen clay in a placer-mine drift on Quartz Creek (Collier, 1902, p. 27) may have come from this stratigraphic unit.*	*Middle member of Kougarok gravel; or late Tertiary age.*
187+	*Coarse white quartz gravel; base not reached in deep shaft near Dahl Creek, a tributary of Quartz Creek.*	*Lower member of Kougarok gravel; probably of middle or late Tertiary age.*

The lignite member was mined near the junction of Turner Creek and the Noxapaga River during the early 1900's for local use. Sainsbury believes the "coarse quartz gravel" is a brecciated quartz vein.

The basin (the Kuzitrin River lowland) is small compared with the uranium-producing basins of Wyoming, but plus factors that probably justify its investigation for bedded uranium deposits are: it is almost completely enclosed; it is poorly drained; and it is surrounded by bedrock that in part could be a source for uranium. Precambrian mineralized metamorphic rocks lie along the northwest side, the Kuzitrin batholith of granite and quartz monzonite is to the east, and Precambrian metamorphic rocks and migmatites intruded by small granite stocks are on the south and southeast.

Small pockets of Tertiary cobble conglomerate are present west of Nome in the Sinuk River drainage area. This area has been described by Hopkins (in Miller and others, 1959, p. 80) as follows:

> *The Sinuk and Stewart Rivers join in an east-northeastward-trending trench that extends from the mouth of the Tisk (Tishue) River to the head of the Nome River. Most of the trench bears a thick mantle of till and outwash. Paleozoic metamorphic rocks crop out in the hills on each side of the trench and also on the east and west ends. However, a small patch of unmetamorphosed coal-bearing sediments is exposed in the valley of Independence Creek, south of the trench. Much of the trench may be underlain by infolded, unmetamorphosed Cretaceous or Tertiary sediments.*

Herreid (1970, p. 10) located other deposits along the banks of Coal Creek and above the ore zone on Aurora Creek. Coalified plant fragments are present, and evidence remains on Coal Creek of early attempts to mine the coal.

Another small interior basin is located in the upper Fish River Lowlands (McCarthy's Marsh), in the south-central part of the Bendeleben quadrangle and the north-central part of the Solomon Quadrangle. Nothing is known about the sediments under the Quaternary deposits in the basin, but the confined shape of the basin and the composition of the nearby bedrocks make it interesting to speculate on the possibility of uranium being concentrated in the sediments. The curving Bendeleben Mountains on the north, the Darby Mountains on the east, and unnamed hills to the south and west form a bowl-shaped basin about 20 miles from east to west and 10 to 15 miles from north to south. The basin is drained by the Fish River, which flows southwest through a narrow valley.

The Bendeleben Mountains contain the Bendeleben batholith and a number of small stocks of quartz monzonite. They generally have a normal uranium background for the rock type. The Darby Mountains consist of York Slate and the Darby batholith. The Darby batholith, consisting mostly of quartz monzonite, has been found to have high backgrounds in uranium and thorium: up to 14.6 ppm uranium and 64.5 ppm thorium (Miller and Grybeck, 1973, p. 6). A uranium-bearing niobate and thorianite have been identified in the batholith. Large amounts of copper, nickel, cobalt, chromium, manganese, iron, boron, scandium, and vanadium were reported from the stream sediments on the eastern side of the intrusive. Numerous gossan zones with high bismuth and molybdenum are present in the northern part of the Darby Mountains. Prospectors have found copper and antimony. The Omilak mine has produced lead and silver from the northwest flank of the Darby Mountains, and the York Slate is apparently the source of a number of placer gold deposits in the area.

The central lowlands and the offshore platforms off western Alaska have been investigated by petroleum companies searching for new petroleum reservoirs, but little information on the sediments is available. Drilling 3 miles offshore from Nome by the U.S. Bureau of Mines led Scholl and Hopkins (1969, p. 2076-2077) and Sainsbury (1970, p. 12) to believe that coal-bearing Tertiary sediments are probably present beneath the Quaternary marine silts, at least along the flanks of the Norton Basin. Most of the Bering Sea Shelf during Tertiary time underwent general subsidence, and Cenozoic sediments accumulated up to 3 km in thickness. Fossil plants collected on St. Lawrence Island, 125 miles southwest of Nome, from Tertiary rocks indicate an Oligiocene age, but Miocene rocks may also be present (Scholl and Hopkins, 1969, p. 2076). The scarcity of information on Mesozoic and Tertiary sediments in the coastal areas and a general lack of knowledge of uranium in this environment prevents the assessment of the uranium potential at present. Sainsbury (1970, p. 12) stated that the Tertiary sediments could contain petroleum, but it is unlikely that any will be found in the older underlying thrust-faulted sediments.

The lowlands of northwestern Seward Peninsula are about 125 miles from east to west and reach a maximum width of 35 miles. The lowlands are the southern part of the Selawik Basin, which includes Kotzebue Sound, part of the Chukchi Sea, Selawik Lake, and the Selawik River lowland. The basin is believed to be a possible petroleum province, and drilling is currently planned by a major oil company. Tertiary sediments occur offshore in the Bering and Chukchi Seas and may extend a short distance landward from the present beaches (Scholl and Hopkins, 1969; Sainsbury, 1972, p. 3). Geophysical surveys indicated at least 2,000 feet of Mesozoic and Tertiary sediments near Kotzebue. Coal of possible Tertiary age has been reported in the coastal plain of Seward Peninsula between Devil Mountain and Shishmaref and also in the headwaters of Espenberg River, a few miles northeast of Devil Mountain (Miller and others, 1959, p. 81).

Kiwalik Lagoon (or bay), immediately north of the village of Candle in the northeastern part of the peninsula and in the extreme northwestern corner of the Candle quadrangle, may contain sediments with anomalous uranium content. Placer gold mining has been conducted in the area since 1901. Drainage is partly from the Granite Mountain and Hunter Creek plutons (discussed on p. 101, 102) which contain anomalously radioactive rocks and where uranium and thorium minerals have been found. Drainage is also partly from Candle Creek, source of a highly radioactive sample.

A sample of heavy minerals concentrated from a sluice box on Candle Creek consisted of a highly radioactive, black cubic mineral questionably identified as uraninite. The sample assayed above 5 percent eU and 3.8 percent U (Hardner and Reed, 1945, p. 14, Table 1, and sample 371 in the appendix). A second sample (No. 22) from the same area assayed 0.049 percent eU. Minerals reported in the sluice boxes included gold, arsenopyrite, pyrite, galena, chalcopyrite, magnetite, ilmenite, rutile, zircon, garnet, cerusite, and hematite. During a later investigation (Gault and others, 1953, p. 11-14), 16 samples were collected from the Candle Creek area. The eU content of these ranged from 0.001 to a maximum of 0.025 percent, and there may be a question as to the correctness of the locations of the earlier, more highly radioactive samples. A small area of schistose and gneissic rock near the head of Potato Creek, believed to be altered acidic intrusive rock, may be the source of the radioactive minerals in Candle Creek.

A U.S. Geological Survey Trace Elements Preliminary Reconnaissance report (No. A 1,739, Matzko, 1954) recorded granitic float between the Kiwalik River and Candle Creek that produced 0.25 mr/hr where the background was 0.05 mr/hr. The anomaly was first detected during an airborne radiometric traverse.

Bedrock surrounding the submerged Imuruk Basin and the lower Kuzitrin River lowland east of Teller is mostly Precambrian schists and marbles with minor gabbro and diabase (Sainsbury, 1974). There is no information to indicate the presence of nonmarine Mesozoic or Teritary sediments, but the area may warrant investigation. The entire basin-lowland is 30 miles long from east to west and about 8 miles wide. The Kigluaik Group of Precambrian rocks in the Kigluaik Mountains south of the basin area consists predominantly of carbonates, but includes dikes, pods, and lenses of granitic gneisses with numerous coarse-grained pegmatites. The Rh-Sr age of these rocks is 750 m.y. (Sainsbury, 1970, p. 4). Small Cretaceous intrusives ranging from gneissic granite to diabase are also exposed along the north side of the Kigluaik Mountains. The Precambrian granite gneisses and Cretaceous intrusives may be favorable source rocks, but their distribution is probably too limited to have supplied substantial uranium to the sediments. The Kigluaik Mountains area itself may, however, be favorable for vein-type uranium deposits. The Pilgrim Springs area, near the eastern end of the lowland, is considered to be a potential source of geothermal power (Homan, 1972, p. 65-66).

The Golovnin Lagoon-Lower Niukluk River lowland on the south-central coast of the Seward Peninsula extends 16 miles northwest from Golovin to White Mountain. Non-marine Mesozoic or Teritary sediments are not known, but the types of bedrock bordering the lowlands are favorable as uranium source rocks. The Kachauik and Darby plutons to the east of the lowlands form a complex about 15 miles wide. They consist of quartz-monzonite, monzonite, syenite, and a migmatitic zone. Precambrian marble, York Slate, and Devonian carbonates are present to the north and east. The York Slate has been the source of placer gold in the area.

Allanite, monazite, and an unidentified niobate mineral was found in placers along the east shore of Golovnin Bay (Bates and Wedow, 1953, p. 5-6). The niobate mineral was recognized in a concentrate from slope wash on the beach about midway between Cheenik and Mission Creeks near a contact between two intrusive bodies. The most radioactive sample contained about 0.08% eU from a heavy mineral fraction. Farther south along the Golovnin Bay coast, another slope-wash sample contained monazite and traces of allanite. The samples yielded about 0.05 percent eU. Other radioactive concentrates from the Golovnin Bay area had from 0.01 to about 0.03 percent eU. The possibility of uranium-bearing clastics in the lowlands or on the slopes of the batholiths may be worth considering.

Igneous Rocks

The composition and associated minerals of many of the intrusive rocks on the Seward Peninsula are favorable for urnaium. Several localities have been found to contain anomalously high amounts of uranium, and uranium minerals have been identified, so that the plutonic bodies of the region are of particular interest to this study. (The granitic rocks of the Granite Mountain and Hunter Creek plutons in the Candle quadrangle in easternmost Seward Peninsula are not considered here, as they belong to the plutonic belt of west-central Alaska.)

The intrusive rocks of the Seward Peninsula are principally of Jurassic or Cretaceous ages, and many intrude polymetamorphic rocks of Precambrian and Paleozoic ages. Precambrian intrusive rocks are present as gneisses in the Kigluaik Mountains and possibly in a belt in south-central Seward Peninsula. Paleozoic gneisses include some granitic rocks in the interior. The principal areas containing Jurassic and Cretaceous intrusive rocks are the Darby Moutnains in south-central Seward Peninsula, the Kwiktalik Mountains adjacent to the southern part of the Darby Mountains, and the Bendeleben Mountains in the central part of the peninsula. Smaller plutons are present north and west of the Bendeleben Mountains; on the western end of the Kigluaik Mountains; and at several isolated localities as at Ear Mountain, Brooks Mountain, Black Mountain, and Cape Mountain in the western York Mountains, Kilwalik Mountain in east-central Seward Peninsula, and at Serpentine Hot Springs. Granite also underlies the Lost River Mine area and probably the Potato Mountain area at shallow depths.

Extensive Quaternary lava fields cover several hundred square miles in the interior and on the northernmost projection of the peninsula in the area of Devil Mountain and northward.

The main characteristics of selected plutons on the Seward Peninsula are outlined below.

Darby Pluton

The Darby pluton is probably the most interesting of the plutons on the peninsula for uranium exploration. It is the largest, extending 50 miles NNE from Cape Darby and averaging about 4 miles in width. It contains anomalous amounts of uranium and a variety of other metals.

Location	:	Darby Mountains, southeastern Seward Peninsula.
Approximate size	:	200 square miles.
Main rock types	:	Leucocratic, massive coarse-grained quartz monzonite cut by aplite and alaskite dikes.
Age	:	K-Ar dates of 81.4 and 92.1 m.y.
Mineral occurrences	:	Anomalous Zn, Ag, Au, Sn, Sb, Pb, in sediment; lead-silver mine; tin and copper prospects; over 10,000 ppm bismuth and 100 ppm Mo in gossans.
Radioactivity	:	Rock analyses produced 8.8 to 14.6 ppm uranium and 48.8 to 64.6 ppm thorium. Up to 0.1% eU produced from stream concentrates. Thorite identified on south end of pluton, and uraniferous niobate contained 70 ppm uranium.
References	:	Bates and Wedow, 1953; Herreid, 1965; Miller and others, 1972; West, 1953.

Kachauik Pluton

Location	:	West flank of Darby Mountains and Kwiktalik Mountains, southeastern Seward Peninsula. Separated from the south end of the Darby pluton by a 2-mile-wide migmatitic zone.
Approximate size	:	30 miles long (north-south) and up to 8 miles wide; 180 square miles.
Principal rock types	:	Leucocratic to mesocratic coarse-grained monzonite and syenite cut by alkaline dikes, hybrid diorite, granodiorite, and gneissic monzonite.
Age	:	K-Ar dates of 97.5±3 m.y. and 86.1±3 m.y.
Mineral occurrences	:	Two occurrences of tungsten reported on coast of Golovnin Bay. Scattered copper and lead anomalies in sediment samples.
Radioactivity	:	The heavy fractions of concentrates from most of the streams draining the west slope of the pluton were tested; maximum eU was 0.028%, probably due to sphene and zircon. Niobate material from slope wash on beach to Golovnin Bay had eU content of 0.08%.
References	:	Miller, 1973; Miller and others, 1972; Lu and others, 1967, fig. 3; and West, 1953, p. 4.

Bendeleben Pluton

Location	:	Bendeleben Mountains, central Seward Peninsula.
Approximate size	:	Elliptical, 18 by 8 miles; 145 square miles.
Principal rock types	:	Leucocratic and fine- to-medium-grained quartz monzonite and granodiorite, cut by aplite and alaskite dikes. Surrounded by a migmatic zone up to 1 mile wide consisting of Precambrian York Slate and Nome Group rocks cut by Cretaceous granitic dikes and stocks.
Age	:	K-Ar date of 79.8±2.4 m.y.
Mineral occurrences	:	Not reported within the Bendeleben pluton.
Radioactivity	:	Granitic bedrock has 1.8 to 4.4 ppm U and 16.9 to 21.4 ppm Th, considered normal for average granites.
References	:	Miller and others, 1972; Miller and Grybeck, 1973; and Sainsbury, 1974.

Windy Creek Pluton

Location	:	Ridge between the north end of the Darby pluton and the east end of the Bendeleben pluton, in fault contact with the southeastern edge of the Bendeleben pluton.

Size	:	3 by 6 miles; 18 square miles.
Principal rock types	:	Leucocratic, massive monzonite and quartz monzonite; includes some nepheline syenite. Similar to Granite Mountain pluton, 40 miles to the east.
Age	:	Tentatively assigned a mid-Cretaceous age.
Mineral occurrences	:	Pluton is considerably fractured in part and is hydrothermally altered; weathers rusty orange. Mo, Pb, Zn, and Ag anomalies in stream sediments. Fluorite is associated with the pluton itself, and the northwest-trending fault that forms the western boundary of the pluton has been mineralized with quartz and fluorite for at least 3,000 feet.
Radioactivity	:	A radioactive anomaly where the total count is more than twice the background within the stock was detected from the air; it has not been checked on the ground.
References	:	Miller and others, 1971; Miller and others, 1972; Miller and Grybeck, 1973; and Sainsbury, 1974.
Note	:	Most of the Windy Creek stock has been staked by Placid Oil Company.

Kutzitrin Lake Batholith

Location	:	Northern flank of the Bendeleben Mountains, 2 to 4 miles form west end of the Bendeleben pluton; well exposed around Kutzitrin Lake. A belt of quartz monzonite stocks extends north for 20 miles from Kutzitrin Lake batholith to Black Butte.
Age	:	Late Jurassic or early Cretaceous.
Principal rock types	:	Largely coarse-grained biotite quartz monzonite or granite. Sphene is extremely abundant, and zircon and allanite are recognized locally.
Mineral occurrences	:	Not reported.
Radioactivity	:	The plutons in this group do not seem to have been investigated.
References	:	Hopkins, 1963; Sainsbury, 1974.

Serpentine Granite

Location	:	Serpentine Hot Springs area, northwest corner of Bendeleben quadrangle; forms a 2,592-foot-high mountain.
Approximate size	:	25 square miles, roughly oval.

Principal rock types : Pluton is composed of several facies; borders are coarsely porphyritic biotite granite; the internal facies is more quartz-rich and higher in trace elements. Pluton cut by granite, diabase, and lamprophyre dikes.

Age : Cretaceous or Tertiary; absolute age not determined.

Mineral occurrences : Two mineralized fault zones at least 2,500 feet long contain highly anomalous amounts of metals, including Au, Ag, Pb, Hg, As, Cu, Mo, Sn, Sb, Zn, and W. Placer gold mined on Humbolt Creek and cassiterite nuggets up to 3 inches in diameter were recovered in the sluice boxes.

Radioactivity : Most phases of the Serpentine granite show radioactivity in excess of that for normal granites. The eU of 29 samples of granite averaged 0.008%. Heavy mineral fractions averaged 0.064% eU. An airborne radiometric survey of the area defined several anomalies in the Serpentine granite, some up to eight times that of surrounding areas. A concentrate sample from Harris Creek on the north side of Harris Dome, 15 miles south of Serpentine Hot Springs, yielded 1.335% eU and 0.08% U.

References : Moxham and West, 1946, Sainsbury, 1974, p. 15; Sainsbury and others, 1968, 1970, Harder and Reed, 1945, p. 14-15, table 1.

Brooks Mountain

Location : Northeast of the York Mountains near the center of the Teller quadrangle, 10 miles from the coast to the south.

Approximate size : 2 square miles; a small isolated stock; altitude 2,898 feet.

Age : K-Ar date of 75.1 ± 3 m.y.

Principal rock types : Medium- to coarse-grained biotite granite and biotite-hornblende granite cut by granite and aplite dikes. The stock cuts Precambrian black slate and limestone and Paleozoic carbonates. Common minerals include orthoclase, plagioclase, biotite, smoky quartz, and black tourmaline, with accessory monazite, zircon, xenotime, anatase, magnatite, and ilmenite.

Mineral occurrences : A large variety of minerals found near hydrothermally altered contact zones between limestones and granite and in veins in limestone. Tin minerals in limestone at Brooks Mountain consist of cassiterite, hulsite, and paigeite intergrown with galena, pyrrhotite, and sphalerite. The gangue consists of fluorite, axinite, tourmaline, calcite, idocrase, diopside, and phlogopite. Small amounts of scheelite, arsenopyrite, pyrite, tetrahedrite, bismuth, azurite, malachite, siderite, cerussite, and zunerite are present. Also stibnite, beryllium, copper, lead, silver, zinc, and rare earths have been reported in the area. Apparently no ore has been produced.

Radioactivity	:	Zeunerite, a hydrous copper-uranium arsenate, is the principal uranium mineral. It was found at two places on the southwest flank of Brooks Mountain, where it is disseminated in hematite and lines vugs in pegmatitic granite and as coatings on quartz-tourmaline veins. The maximum eU obtained was 2.1% from float. The overall average for the lens or rock surrounding the deposit is about 0.07%. The average for the entire granite is about 0.005% eU. Trace amounts of zeunerite found as an impurity in a number of accessory minerals and in granite at three localities other than the zeunerite locations.
References	:	Sainsbury, 1972; White and others, 1952; West and White, 1952; Cobb and Sainsbury, 1968; Berg and Cobb, 1967, p. 133; Steidtman and Cathcart, 1922.

Black Mountain Stock

Location	:	18 miles northwest of Teller, southeast of York Mountains, 8 miles from coast.
Approximate size	:	3/4 mile in diameter.
Main rock types	:	A small biotite granite stock intrudes Pre-Ordovician slates, phyllites, and arillaceous limestones in the Seward Peninsula tin belt. The slates are locally intruded also by Pre-Ordovician medium- to coarse-grained gabbro.
Age	:	Late Cretaceous.
Mineral occurrences	:	Minerals are along fault zones and contacts that contain up to several-percent sulfides. Minerals reported include garnet-rich tactite, galena, sphalerite, pyrite, arsenopyrite, quartz, topaz, fluorite, traces of gold and silver, and an unidentified sooty-black mineral. Veins can be traced for up to 5,000 feet.
Radioactivity	:	No information, but the mineralogy and the 'unidentified sooty-black mineral' suggest possibilities for uranium occurrences.
Reference	:	Sainsbury and Hamilton, 1967, p. B21-25.

Cape Mountain

Location	:	Westernmost top of Seward Peninsula, on coast at Cape Prince of Wales, Teller quadrangle.
Approximate size	:	10 square miles; altitude 2,250 feet.
Age	:	Upper Cretaceous.
Principal rock types	:	Medium- to coarse-grained biotite granite; intrudes Paleozoic limestone.

Mineral occurrences	:	Lode and placer tin produced. Veins in fractures along granite limestone contact. Geochemical sampling showed anomalous amounts of beryllium.
Radioactivity	:	Concentrates from Cape Mountain placers contain as much as 0.9% eU and 28 samples average about 0.03% eU because of monazite, xenotime, and zircon, probably derived from the granite, but may be related to tin deposits. Anomalous samples were collected from Village, Boulder, Granite, and Cape Creeks and Pauline and Goodwin Gulches.
References	:	Sainsbury, 1972, 1963; Wedow and others, 1953; Mulligan and Thorne, 1959; Hardner and Reed, 1945, p. 7-12, table 1.

Ear Mountain Intrusive

Location	:	Northwestern Seward Peninsula, north-central part of the Teller quadrangle, about 15 miles from the northwest coast.
Approximate size	:	An isolated stock about 2 miles in diameter, 4 square miles in area, altitude 2,329 feet.
Age	:	Upper Cretaceous.
Principal rock types	:	Porphyritic biotite granite and alaskite dikes and sills intruded into Port Clarence Limestone.
Mineral occurrences	:	Tin is the most important metal; it has been mined from lode and placer deposits. Copper, lead, zinc, antimony, gold, and silver are present in small amounts in the granite-limestone contact zones. Anomalous amounts of beryllium found by geochemical sampling. Red hematite associated with radioactive veins.
Radioactivity	:	A maximum eU of 0.290% was obtained from panned concentrates and a maximum of 0.01 from a mine shaft. A quartz-tourmaline vein in a mafic dike contained up to 0.045% eU and 0.035 U by chemical analysis. Anomalous amounts of radioactivity from many of the 100 stream-concentrate samples collected in the area ranged from 0.001 to 0.290 percent eU.
References	:	Killeen and Ordway, 1955; Mulligan, 1959; Sainsbury, 1963; Berg and Cobb, 1967, p. 34.

Kigluaik Mountains Batholith

Location	:	Southwestern Seward Peninsula, western part of the Kigluaik Mountains.
Size	:	The main intrusive body is about 12 miles long and 3 to 4 miles wide. Numerous satellitic intrusive bodies present.
Age	:	Cretaceous.

Principal rock types	:	The Cretaceous granitic rocks form a complex of biotite granite with a darker border phase. Numerous younger fine-grained granites and mafic dikes intrude the complex. Alkalic rocks common to the granitic complexes of the eastern Seward Peninsula are not present in this complex.
Mineral occurrences	:	A number of lode prospects are in the Kigluaik Mountains. Though not necessarily within granites, but assumed to be genetically related to them, are anomalous amounts of silver, beryllium, bismuth, arsenic, gold, mercury, molybdenum, lead, antimony, tin, and tungsten. Graphite occurs extensively on the north flank of the mountains in schists, gneiss, and marble. Fluorite deposits have recently been found in brecciated carbonate pipes near a small boss. Part of the area is described as a bismuth-rich province.
Radioactivity	:	The youngest suite of granitic rocks consists of numerous fine- to-medium-grained biotite granite that tends to be unusually rich in thorium and is characterized by large amounts of brownish-red allanite.
References	:	Sainsbury and others, 1970, 1972, p. 11, 12; Cobb, 1968.

Precambrian Gneissic Rocks

Location	:	Rocks of Precambrian age are believed to be widely distributed in the southern and western parts of Seward Peninsula. Those of probable granitic origin and of particular interest to uranium investigations are most common in the Kigluaik Mountains. They are also probably present in a 30-mile belt of schistose rocks in south-central Seward Peninsula.
Age	:	Thrust faulting has produced structural complexities and intermixing of the highly metamorphosed rocks so that the ages of many units are uncertain, but rubidium-strontium dates of around 730 m.y. were obtained from gneissic rocks in the Kigluaik Mountains. These gneisses are believed to have been derived from the York Slate and serve to date that unit as Precambrian. The most recent work by Sainsbury places the "Slate of the York region," Kigluaik Group, Tigaraha Schist, and the Nome Series of earlier writers all within the York Slate.
Principal rock types	:	High-rank gneisses and schist in the Kigluaik Mountains and Bendeleben Mountains contain notable amounts of graphite as well as large blocks of graphite that have been cut by granitic rocks. Some gabbroic bosses have been converted to glaucophane-garnet rocks of the blue-schist facies. Chloritic and graphitic schists are common, and migmatites of Precambrian age form extensive zones around the larger Cretaceous plutons.

Mineral occurrences	:	Widely distributed placer gold is believed to have been derived from the York Slate.
Radioactivity	:	No information is available on the radioactivity of the Precambrian rocks.
References	:	Sainsbury, 1974; Sainsbury and others, 1972.

Extrusive Rocks of Tertiary to Recent Age

Large areas in the northeastern, central, and the northwestern tip of Seward Peninsula are covered by thick layers of volcanic rocks ranging in age from slightly over 3 million years to Recent (Sainsbury, 1974, p. 12). The volcanic rocks on the northwestern tip, mostly north of Devil Mountain, are chiefly basaltic ash; elsewhere they are mostly basalts and andesites. Hopkins (1963) applied the collective name Imuruk volcanic fields to these areas and divided the rocks into several distinct formations. Dozens of volcanic vents have been mapped (Hopkins, 1963, plates 2, 4). Volcanic agglomerate and cinder form small cones at some of the vents. A thin but widespread layer of brown ash was erupted from a center in the Imuruk Lake area.

Structure

Thrust faulting of the Seward Peninsula during two different ages of the Cretaceous period has produced intimate intermixing of Precambrian and Paleozoic rocks and in places created melanges. Cretaceous rocks were also involved in thrusting. Following the thrusting, the thrust sheets were fragmented by many normal faults and intruded by stocks and batholiths ranging in age from 100 to 75 m.y. (Sainsbury, 1972, 1974). The Kigluaik Mountains are a host of older rocks bounded on the north and south sides by normal faults. Periods of moderate deformation occurred during Tertiary time. Coal-bearing rocks of probable Tertiary age are deformed and crop out in small areas.

Economic Geology

The Seward Peninsula is considered to be one of the most highly mineralized regions in Alaska. Most of its lode deposits are in the Precambrian and Paleozoic metamorphic rocks near granitic intrusives, as indicated in the descriptions of plutons in the preceding section. The mineral commodities include gold, silver, platinum, tin, tungsten, beryllium, copper, lead, iron, zinc, antimony, mercury, bismuth, molybdenum, manganese, arsenic, iron, mica, fluorite, and graphite. Placer gold and tin have been the most developed and produced. For summary descriptions of the large number of mineral occurrences, mines, and prospects, the reader is referred to Berg and Cobb (1967, p. 107-135) and Lu and others (1968). The metallogenic map (fig. 32) broadly outlines the principal metals of the Seward Peninsula by areas. The potential for some of these has been discussed by Anderson (_in_ Heiner and Wolff, 1968, p. 279-282). The mineralogy of many lode deposits is favorable for uranium, especially those containing one or more minerals of copper, silver, molybdenum, bismuth, tin, and fluorite.

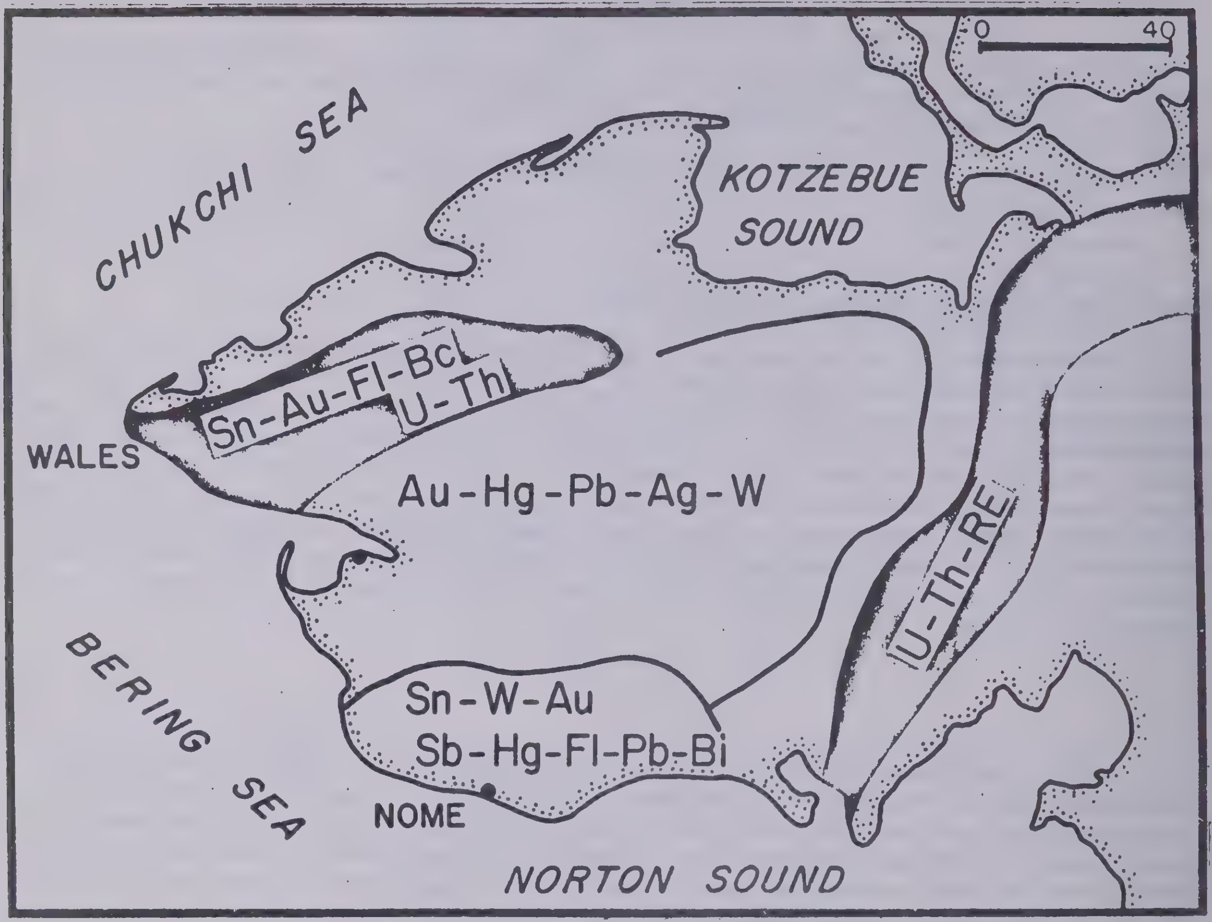


Figure 32. Metallogenic provinces of Seward Peninsula

The York region is the largest domestic source of tin and fluorite and a major source of bismuth and tungsten. Small amounts of platinum (as a by-product of placer gold mining), antimony, bismuth, copper, lead, and mercury have also been mined but so far have not become important. Radioactive minerals have been found but none have been mined. A large-scale project is in progress to develop and mine the fluorite-tin-tungsten deposits at Lost River, near the coast in the York Mountains. Beryllium ore in the Lost River area consists of replacement veins and pipes in limestone in a zone about 7 miles long and 2 to 3 miles wide.

As a result of the increased price of gold, dredges are being reactivated in the Nome district. Approximately 100 lode deposits that were the source of the gold placers at Nome are known. These are mostly base-metal veins of antimony, copper, lead, and zinc. Gold and scheelite are major metals in some veins, but generally are minor constituents. Many of the veins are high grade, but none have been found to be large enough to be of economic importance.

Radioactivity Investigations

More radioactivity investigations have probably been conducted on the Seward Peninsula (fig. 33) and more radioactive deposits found than in any area of comparable size in Alaska. The results of the investigations are summarized in table 3.

Attention is also directed to the metallogenic map (fig. 32) in which a belt of uranium, thorium, and rare earths (RE) extends from the Darby Mountains northeastward to include the Granite Mountain, Hunter Creek, and Selawik plutons. The plutons in this province seem to offer excellent possibilities for the discovery of vein-type radioactive deposits. A second belt with radioactive anomalies consists of the several relatively small stocks in northwestern Seward Peninsula.

Discussion

Known exposures of Tertiary and Cretaceous nonmarine deposits onshore are very limited, but the basin of the upper Kuzitrin River contains coal-bearing sediments of unknown extent and thickness and probably offers the largest area to explore for bedded deposits. Favorable granitic rocks border Golovnin and Kiwalik Lagoons and the upper Fish River Basin. These are relatively small features and no information is available on the sediments, but their close proximity to possible source rocks and known radioactivity anomalies are very encouraging. The Imuruk Basin is larger, but the surrounding bedrock seems less favorable as a source area than at other localities.

Scattered occurrences of Late Cretaceous or Early Tertiary coal-bearing deposits are present along the Kugruk River, on the northernmost tip of the peninsula north of Devil Mountain, and in the Sinuk River drainage. The deposits are small and offer little encouragement for locating commercial uranium, but they lend support to the belief that more extensive nonmarine or marginal marine sediments are present offshore beneath Kotzebue and Norton Sounds. All the coal occurrences should be tested to determine if they are uraniferous. There are no reports of any investigations of the Cretaceous or Tertiary sediments for radioactivity. Drilling presently planned by petroleum companies will aid in assessing the uranium potential of the offshore areas.

The geology of the Seward Peninsula is very favorable for vein-type uranium deposits. Occurrences similar to those at the Marysvale district, Utah, the Schwartzwalder mine in Colorado, and the Midnight mine in Washington may very well exist in this region. Very little work and practically no drilling has been done to explore the known radioactive localities. Structural and petrographic studies might aid in better defining trends and controls of the radioactive deposits.

Numerous small acidic granite stocks that resemble those generally considered favorable for uranium are widespread in the peninsula. Particularly anomalous radioactivity has been found at the Darby Mountains, Cape Mountain, Brooks Mountain, Serpentine Hot Springs, Harris Creek on Harris Dome, and at Candle Creek. Although untested, the Black Mountain area seems to be geologically favorable. A possible uranium-thorium province in the northwestern segment of the peninsula seems to be defined by anomalous radioactivity at Ear, Brooks, and Cape Mountains, and Serpentine Hot Springs. Additional radiometric and geochemical surveys should be used to select drilling targets in these areas.

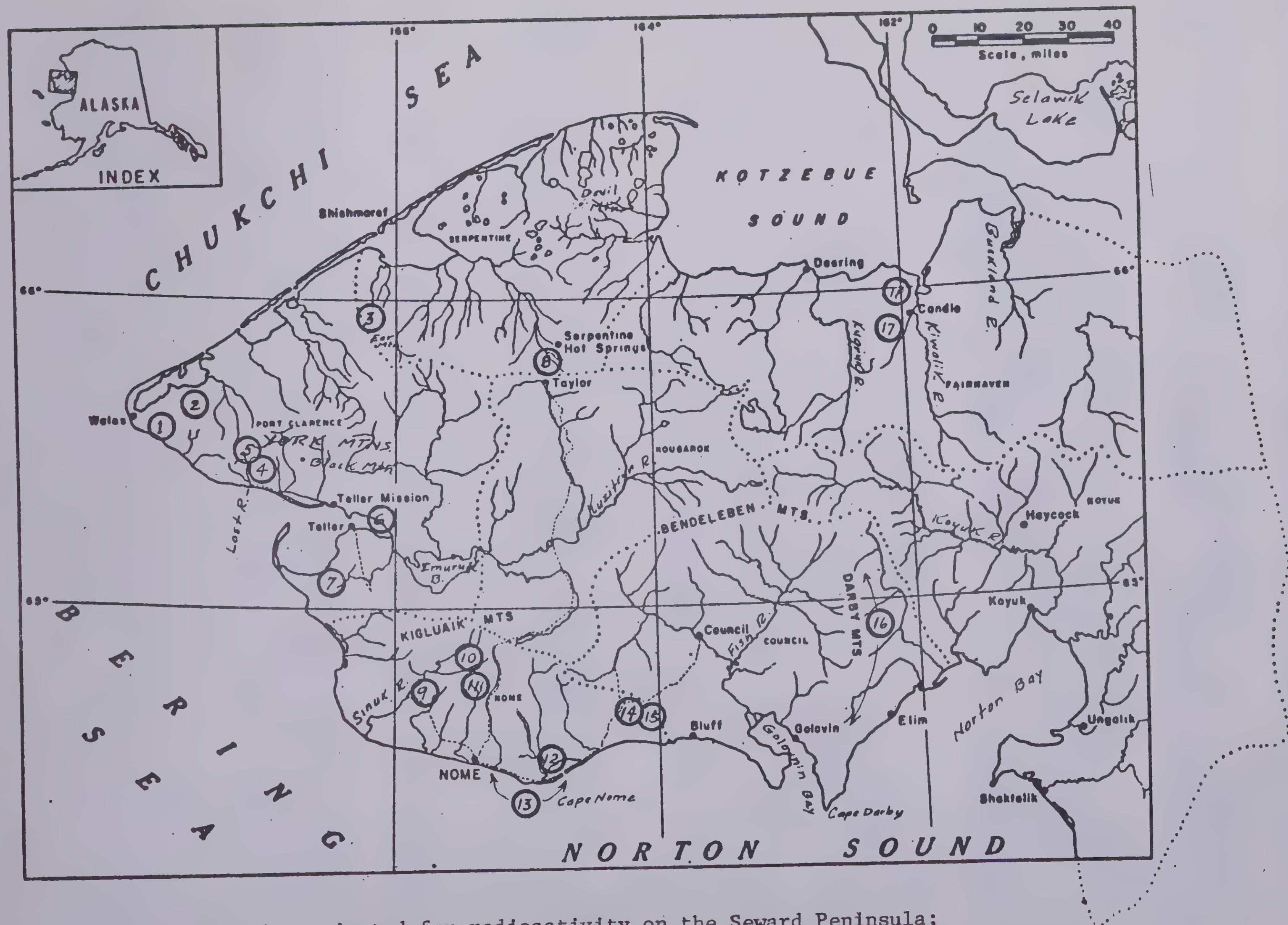


Figure 33. Areas investigated for radioactivity on the Seward Peninsula; see table 3.

TABLE 3. Radioactivity Investigations, Seward Peninsula

Map ref. No.	Locality name	Quadrangle	References to radioactivity investigations	Country rock	Mineralization	Radioactivity measurement or U assay
1.	Cape Mt. area, York district	Teller C-6	Mulligan and Thorne, 1959, p. 66, Bates and Wedow, 1953, p. 6; Wedow and others, 1951, p. 31; Hardner and Reed, 1945, p. 7-12	Granite, limestone, sandstone, slate, basic dike rocks	Sn is important in veins and placer deposits; veins in both granite and intruded limestone. Pyrite, sphalerite, and radioactive hematite present.	eU of concentrates up to 0.9%; average 0.03%, probably due to Th in zircon, monazite, and xenotime.
2.	Potato Mt. area, York Dist.	Teller C-6	Wedow and others, 1951, p. 28-29; White and others, 1952, p. 3	Early Paleozoic black slate intruded by granite porphyry dikes and quartz dikes of Mesozoic age.	Sn, fluorite in veins and placers. Minor hematite, tourmaline, and rutile.	Less than 0.001% eU from concentrate.
3.	Ear Mt., York Dist.	Teller C-4	Wedow and others, 1951, p. 29-31; Killeen and Ordway, 1955	Schistose limestone, shale, slate, quartzite. Granite gabbro, alaskite dikes	Primarily Sn prospects; traces of Cu, Au, Pb, Zn. Most of the radioactivity found was in margins of granite and in quartz-tourmaline veins and with red hematite.	Stream concentrates yielded up to 1.0% eU in heavy mineral fraction. Average for all concentrates collected was 0.031% eU. Radioactivity believed due to monazite and zircon. One piece of ore had 0.182% eU. A radioactive dike is traceable for 5,000 ft; an 18-in. hematite zone in dike had 0.035% U; metazeuner identified.

TABLE 3. Radioactivity Investigations, Seward Peninsula, cont.

Map ref. No.	Locality name	Quadrangle	References to radioactivity investigations	Country rock	Mineralization	Radioactivity measurement or U assay
4.	Lost River area	Teller	Sainsbury, 1964, p. 10, 27; White and West, 1953; Wedow and others, 1951, p. 22-25, Wedow, 1956, p. 49	A granite pluton does not crop out. Many veinlets and dikes cut Ordovician limestone which is marmorized and partly replaced.	Principal minerals are Sn, W, fluorite, and Be. Hematite, tourmaline, minor sulfides present. Sn has been mined; fluorite, Sn, and W are being developed for large-scale mining. Rare-earth elements identified.	Sn bearing rhyolitic dikes contain as much 0.01% eU; a pocket of iron oxide in limestone contains about 0.06% eU. Dikes average 0.005% eU.
	Brooks Mountain area	Teller	West and White, 1952; Wedow and others, 1951, p. 26-28; Wedow, 1956, p. 49	A granitic stock and felsic and mafic dikes intrude Precambrian black slate and Paleozoic limestone.	A large variety of contact metamorphic minerals and sulfides present. Also Sn, W, and hematite.	Metazeunerite (previously identified as zeunerite) occurs with hematite in a lens-shaped body of altered coarse-grained granite at a granite-limestone contact. Although selected specimens of the deposit contain more than 2% U, the average content is between 0.1 and 0.2%. Metazeunerite also occurs as surface coating of tourmaline veins cutting the granite and as traces in a base-metal lode also at the granite-limestone contact. The lens-shaped body was about 15 feet in diameter and 4-5 feet thick. Average eU of granite = 0.005%

TABLE 3. Radioactivity Investigations, Seward Peninsula, cont.

Map ref. No.	Locality name	Quadrangle	References to radioactivity investigations	Country rock	Mineralization	Radioactivity measurement or U assay
6.	Teller area, north side of Grantley Harbor.	Teller B-3	White and others 1953, p. 1-4	Schist, limestone, slate and greenstone of probable Precambrian age	Placer Au; quartz veins	Maximum eU from stream concentrates = 0.004%
7.	Teller area	Teller A-3	White and others, 1953, p. 1-4	As above	As above	Maximum eU from stream concentrates = 0.004%. Heavy-mineral fraction from a granite boulder contained 0.017% eU due to allanite and zircon.
8.	Serpentine-Kougarok area	Bendeleben C-6, D-6	Moxham and West, 1946; Sainsbury and others, 1970; Hardner and Reed, 1945, p. 14-15	A porphyritic biotite granite stock intrudes Precambrian metamorphic rocks and Paleozoic greenstone	Placer and lode Au; minor placer Sn; Cu, W, and Hg prospects. Au Ag, Hg, As, Co, Cu, Mo, Bi, Pb, Sb, Sn, W, and Zn occur in stream concentrates and in altered bedrock at Serpentine Hot Springs granite area.	Average eU of 29 samples of granite = 0.008% and their heavy-metals portion averages 0.034%. Highest radioactivity was found near Hot Springs Creek. Maximum eU of crushed granite = 0.032%. Several airborne radiometric anomalies mapped over Serpentine Hot Springs granite not checked on the ground.
9.	Sinuk River iron area	Nome D-2	White and others, 1952, p. 4	Early Paleozoic limestone	Veins and stockworks and limonite and hematite; also magnetite, Mn, Pb, Zn, and Au	eU less than 0.001%
10.	Charley Cr. bismuth prospect, Nome district.	Nome D-1	White and others, 1952, p. 4	Early Paleozoic schist	Bi with pyrite	eU less than 0.002%

TABLE 3. Radioactivity Investigations, Seward Peninsula, cont.

Map ref. No.	Locality name	Quadrangle	References to radioactivity investigations	Country rock	Mineralization	Radioactivity measurement or U assay
11.	Red and Strand mine, Nome district	Nome D-1	White and others, 1952, p. 4	Early Paleozoic schist	Quartz veins, Sb, pyrite, arsenopyrite	eU = 0.001%
12.	Cape Nome area	Nome B-1, C-1, Solomon B-6, C-6	Bates and Wedow, 1953, p. 12; White and others, 1953, p. 5-8	Complex of granite, gneiss, schist, greenstone of Paleozoic to Mesozoic ages	Placer Au on beach. Small amount of allanite in granite	eU of concentrates of crushed rock = 0.001 to 0.012%, and slopewash concentrates had eU from 0.006 to 0.025%
13.	Road traverses, Nome area	Solomon, Nome	White and others, 1952, p. 4	Schist, granite, gravels, limestone, slate	Sb, pyrite, arsenopyrite	No important anomalies detected
14.	Quiggley (Grey Eagle) antimony prospect	Solomon C-5	White and others, 1952, p. 4	Quartz veins in Carboniferous slate	Sb	eU under 0.001%
15.	Big Hurrah mine	Solomon C-5	White and others, 1952, p. 4	Carboniferous black slate intruded by quartz vein	Au, Cu, Sb, and pyrrhotite in veins	eU under 0.001%
16.	Darby Mts.	Solomon, west half	West, 1953; Miller and Grybeck, 1973 p. 5, 6; Bates and Wedow, 1953, p. 5	Core of mountains is Cretaceous quartz monzonite; smaller plutons of syenite, nephelene syenite, and diorite. Dikes of aplite, latite porphyry, and alaskite. All intrude Precambrian metamorphic rocks.	One Ag-Pb mine; placer Au; Cu prospects; numerous gossans; Cu, Pb, Zn, Au, As, Nb, and Sn in anomalous amounts in stream-sediment and bedrock samples	Concentrates in Clear Creek area yielded up to 0.104% eU. Thorianite and a uranium-bearing niobate mineral found on east side of Darby pluton and on Golovnin Bay. The pluton has a high U and Th background: 8.8 to 14.6 ppm U and 48.8 to 64.6 ppm Th.

TABLE 3. Radioactivity Investigations, Seward Peninsula, cont.

Map ref. No.	Locality name	Quadrangle	References to radioactivity investigations	Country rock	Mineralization	Radioactivity measurement or U assay
17.	Candle area, ridge at head of Montana Cr.	Bendeleben D-1	Sandvik, 1956	Schist	Earlier reports of samples from same area containing up to 1.3% U_3O_8 were found to be incorrect by later drilling	Three drill holes from 25' to 63' in depths produced eU from 0.002 to 0.01%
18.	Candle Creek area, northeastern	Candle D-6, Bendeleben D-1	Gault and others, 1953, p. 11-14; Hardner and Reed, 1945, p. 14	Schist cut by rhyolite dikes and sills and small quartz stringers. A small granitic body near head of Candle Creek.	Placer Au. Small amounts of radioactive minerals in placers possibly uraninite-thorianite. Heavy minerals reported from sluice boxes include arsenopyrite, pyrite, galena, chalcopyrite, magnetite, ilmenite, rutile, zircon, garnet, cerusite, and hematite.	eU of placer concentrates ranged from 0.001 to 0.025%. A black cubic mineral reportedly from the Candle Creek area placers was highly radioactive (possibly uraninite); produced over 5% eU.

Precambrian gneissic rocks of possible granitic origin in the Kigluaik Mountains and other areas offer possibilities for vein-type deposits of uranium. These rocks have not received much attention, possibly because they are poorly exposed, are mixed with other types of rock, and are difficult to map.

The possibility of diatremes as a source of uranium in the large areas of lava flows and numerous volcanic vents in the eastern, central, and north-central part of Seward Peninsula may deserve consideration.

THE PELLY GNEISS OF EAST-CENTRAL ALASKA

Extensive uranium deposits have been associated with Precambrian granitic shields in Canada and Africa and granitic gneisses in Australia; therefore, the age of the granitic gneisses associated with the Birch Creek Schist of possible Precambrian age in the Yukon-Tanana region of Alaska was researched.

The granitic gneiss associated with the Birch Creek Schist was tentatively identified by J.B. Mertie (1937, p. 54) as equivalent to the Pelly Gneiss first described by McConnel (1890) in the Yukon Territory. Mertie based his identification on the fact that the Birch Creek Schist appeared to be nearly in contact with relatively unmetamorphosed Tindir Group along the Yukon River. Since the Tindir Group was known to be Precambrian, he inferred that the highly metamorphosed Birch Creek Schist and the gneiss were older than the Tindir Group and similar in age to the Pelly Gneiss of the Yukon Territory. The Tintina Fault zone separates the Tindir Group from the Birch Creek Schist, and its relation to the Tindir Group is uncertain (Foster, 1973, p. 389). Foster and others (1973) state that crinoid columnals and bryozoans have been found in the Birch Creek Schist in the Eagle area, indicating a Paleozoic age. Mertie's Pelly Gneiss, which is fairly widespread in the Eagle area, cuts the Birch Creek Schist and appears to be no older than Early Paleozoic age and possibly unrelated to the Pelly Gneiss in Yukon Territory. Although this granitic gneiss is probably not Precambrian, it may warrant examination for anomlaous uranium content.

According to Mertie (1937, p. 201-203) the Pelly Gneiss in the Yukon-Tanana area of Alaska is typically light colored and displays a secondary structure that ranges from laminated gneissoid to contorted schistose fabric. At some localities, particularly along ridge tops, these gneisses weather residually into monolithic outcrops. The more common gneissoid type is characterized by many augen, usually composed of feldspar up to 3 inches in diameter.

Rocks that appear to be derived from granite, quartz monzonite, granodiorite, quartz diorite, and quartz gabbro have been recognized, although granite is most common. In the granitic types, quartz, orthoclase or microcline, albite, and mica seem to constitute the essential mineral components. The accessory minerals are apatite, zircon, garnet, and magnetite. The secondary minerals are quartz, sericite, several varieties of chlorite, epidote, calcite, and iron hydroxides.

Mesozoic plutons near the gneisses have been mined for copper, and the Birch Creek Schist has been mined for gold. Copper sulphides are associated with the gold deposits (Mertie, 1937). There does not appear to have been any mining in the gneisses.

The Paleozoic or Precambrian granitic gneisses of east-central Alaska have never been mapped as a separate unit. However, they are known to crop out in the Tanacross, Eagle, and Big Delta quadrangles. Any further study as to the uranium content of the Yukon-Tanana Paleozoic-Precambrian granitic gneisses should start with the gneiss mapped as 'augen gneiss' on Foster's (1970, 1972) geologic maps of the Tanacross and Eagle quadrangles.

THE COOK INLET BASIN

The Cook Inlet Basin region in south-central Alaska includes the submerged trough between the Kenai Peninsula and the mainland, the Kenai Peninsula lowlands, and the lower end of the Matanuska Valley (fig. 34). The area is a northeast-trending intermontane basin 200 miles long and 60 miles wide bounded by the southern Alaska Range and Aleutian Range (locally called the Chigmit Mountains) on the northwest and the Kenai and Chugach Mountains on the southeast. The Talkeetna Mountains limit the basin at the northeastern end. The southwestern limit is near the northeastern end of Shelikof Strait. Anchorage, Alaska's largest city, is located at the head of Cook Inlet between Knik and Turnagain Arms.

The Cook Inlet is a major petroleum province where 21 oil and gas fields have produced from the Tertiary Kenai Group. A number of wells have reached a depth of 15,000 feet and one reached 22,000 feet. The Tertiary sequence is believed to attain a thickness of 30,000 feet in the central part of the basin, and the Mesozoic rocks may be as much as 40,000 feet thick (Kirschner and Lyon, 1973, p. 396). In addition to petroleum, the Tertiary rocks onshore contain large reserves of coal.

The coastal lowlands along either side of the inlet are up to 20 miles wide and 50 miles long. These are glaciated areas, generally less than 500 feet in elevation, containing ground moraines, eskers, and many lakes in the outwash plains. Between the lowlands and the bordering mountains are areas of rolling uplands reaching altitudes of up to 3,000 feet.

The Aleutian Range in the Cook Inlet region is narrow, very rugged.and contains numerous glaciers and several quiescent but potentially dangerous volcanoes of the Aleutian volcanic chain, the highest of which is 12,600 feet in altitude. The Chugach and Kenai Mountains are also rugged and contain glaciers and ice fields.

The Cook Inlet Basin lies in a long, narrow trough created in early Middle Jurassic time and now filled with Mesozoic, Tertiary, and Quaternary sediments encompassing about 12,000 square miles. It is part of the Matanuska geosyncline, an arcuate 750-mile-long trough near the northwestern end of the Pacific Cordilleran mobil belt (Payne, 1955). The present Cook Inlet basin is believed to contain 20,000 cubic miles of Tertiary sedimentary rocks with at least 1.5 billion barrels of recoverable oil reserves (Kirchner and Lyon, 1973, p. 396).

Temperatures are relatively mild, but wind storms and fog can create severe flying conditions. Ice in the inlet is a problem to shipping and operation of the offshore petroleum platforms. The normal yearly precipitation at Anchorage is 15 inches, but at the lower end of the inlet may reach 60 inches. The lowlands are free of permafrost, but isolated masses are present at the higher elevations.

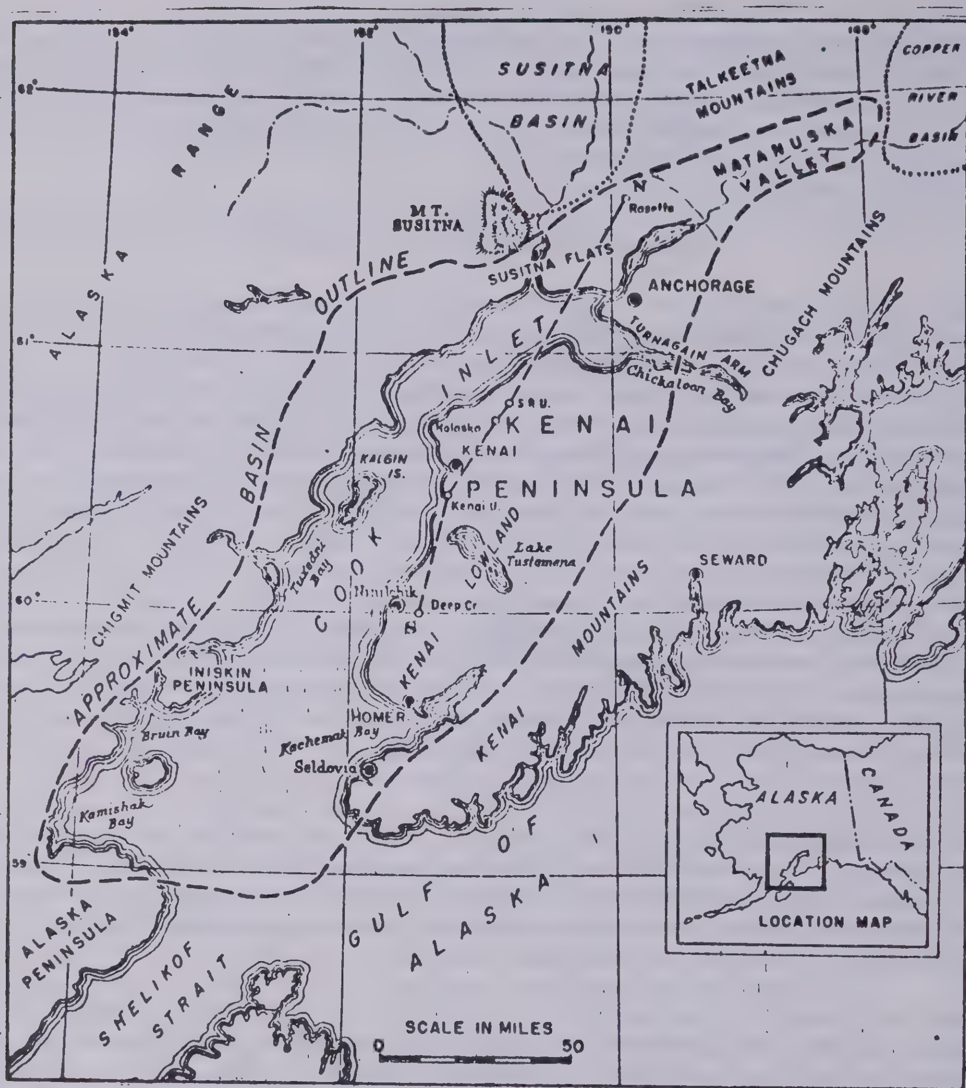


Figure 34. Index map of Cook Inlet Basin, Alaska.

Sedimentary Rocks

Since the discovery of oil in the Cook Inlet Basin in 1957, many wells have provided much subsurface information. Well logs, cores, and samples of well cuttings are on file at the Alaska State Division of Oil and Gas in Anchorage. However, the petroleum industry has not published much of the geological information gathered by their staffs. A listing of logs and samples available for examination has been published by the Division of Oil and Gas (1973), but petroleum companies are not required to release such information until 2 years after completion of wells. Petroleum Publications, Incorporated, Anchorage, also lists the data available of the Cook Inlet in their Catalog of General Services. Published detailed geologic maps of bedrock geology in the Cook Inlet region do not cover the area completely, and correlations between surface

exposures of the Tertiary and the subsurface are incomplete and uncertain. Most of the published investigations of the Tertiary rocks in outcrops are the result of studies of coal resources in the region. The difficulties in establishing correlations within the Tertiary section of the Cook Inlet Basin are attributed to (1) a paucity of fossils, (2) lack of persistent mappable beds in any given formation, and (3) lack of continuity in the Tertiary outcrops.

Published general descriptions of the stratigraphy in the basin and those used for this discussion are those by Adkison and Newman (1973); the Alaska Geological Society (1964, 1968-1969); Calderwood and Fackler (1972); Carter and Adkison (1972); Hartman, Pessel, and McGee (1972); Kelly (1963); and Wolfe, Hopkins, and Leopold (1966). A bibliography of the geological literature of the region has been compiled by Maher and Trollman (1969).

The Cook Inlet Basin contains possibly 40,000 feet of marine Mesozoic strata and up to 30,000 feet of nonmarine and estuarine Tertiary sediments (fig. 35). Three cycles of sedimentation during Mesozoic time and two during Tertiary time were separated by orogenic pulses, each of which caused progressive restriction of the basin and greater emergence of border areas (Kirschner and Lyon, 1973, p. 396).

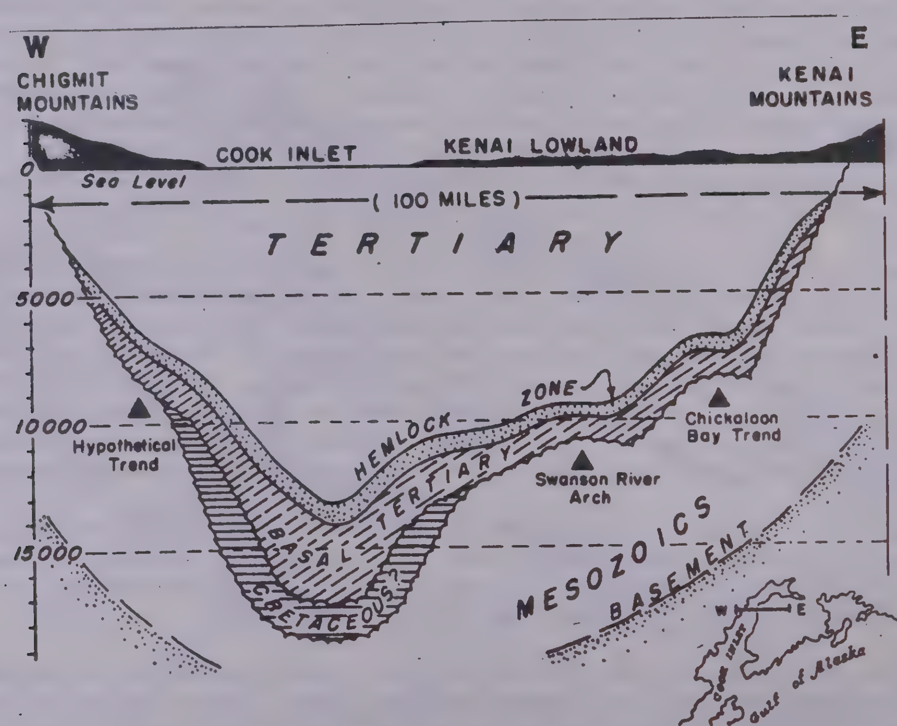


Figure 35. East-west diagrammatic structural cross section of Cook Inlet Basin, Alaska. (Source: Kelley, 1963.)

Mesozoic Sediments

The oldest known rocks are the Permo-Triassic and Early Jurassic sediments that have been penetrated by wells near the basin margins and which crop out along the southwestern part of the province. The Mesozoic section includes many thousands of feet of metavolcanics, slate, crystalline limestone, chert, turbidites, siltstone, and graywacke (fig. 36). The southern Alaska Range and Talkeetna Mountain batholiths were emplaced during mid-Jurassic time. They consist largely of quartz diorite, which is widespread in outcrops and subcrops along the margins of Cook Inlet Basin.

Siltstone and volcanic graywacke of the Jurassic Tuxedni Group and feldspathic, quartzitic graywackes of the Naknek Formation are well exposed in the southern Cook Inlet. The Early Cretaceous Nelchina Limestone is present as a shelf facies in the Copper River Basin and as erosional remnants in the Cook Inlet Basin. The Late Cretaceous Matanuska Formation is widely exposed in the Matanuska Valley and has been penetrated by numerous wells in the Cook Inlet. The Matanuska Formation is up to 10,000 feet thick and consists primarily of siltstone with thin sandstone members.

Mesozoic strata in the basin are generally metamorphosed, of marine origin, and so far have not been found to have significant potential for petroleum. Local nonmarine wedges derived from the rising border areas during orogenic pulses are probably present within the sequence but, for the most part, do not seem to be favorable hosts for uranium deposits. However, some of the Cretaceous units exposed in the Copper River Basin that may be equivalent to sediments in the Cook Inlet appear to have some characteristics of uranium-bearing sediments. Following folding of the Mesozoic sequence during the Laramide orogeny, they were unconformably overlain by Tertiary sediments.

An unusual section of Triassic and Jurassic sediments is exposed on the west side of the lower part of the Cook Inlet, 125 miles southwest of Anchorage. A few small exposures of nonmarine Tertiary sediments are also present in the area. The area where the sediments are exposed is about 45 miles long and up to 20 miles wide between Tuxedni Bay and Iniskin Bay and is referred to as the Iniskin-Tuxedni region. The Chigmit Mountains rise abruptly from the Cook Inlet shoreline. The dominant feature is Iliamna Volcano, which has an altitude of 10,016 feet and feeds glaciers that extend into the Iniskin-Tuxedni region.

Because it is underlain by one of the most nearly complete sequences of Jurassic strata in the United States, the region has been studied by a number of geologists with the U.S. Geological Survey. The following discussion, however, is taken almost entirely from Detterman and Hartsock (1966).

The Triassic rocks in the Iniskin-Tuxedni region consist of metamorphosed limestone, sandstone, shale, and basaltic lava flows. Their thickness ranges from 160 to 1,300 feet. These marine rocks are not of interest to this study and will not be described further.

As much as 26,000 feet of Jurassic sediments are exposed within a few miles of the coast in the region. Although the sediments are mostly of marine origin they should be examined for possible uranium deposits because of the presence of minor amounts of terrigenous sediments, the abundance of volcanic tuffs and arkosic sandstones throughout the section, and the proximity of the large Aleutian Range batholith, which is composed mostly of quartz diorite to quartz monzonite.

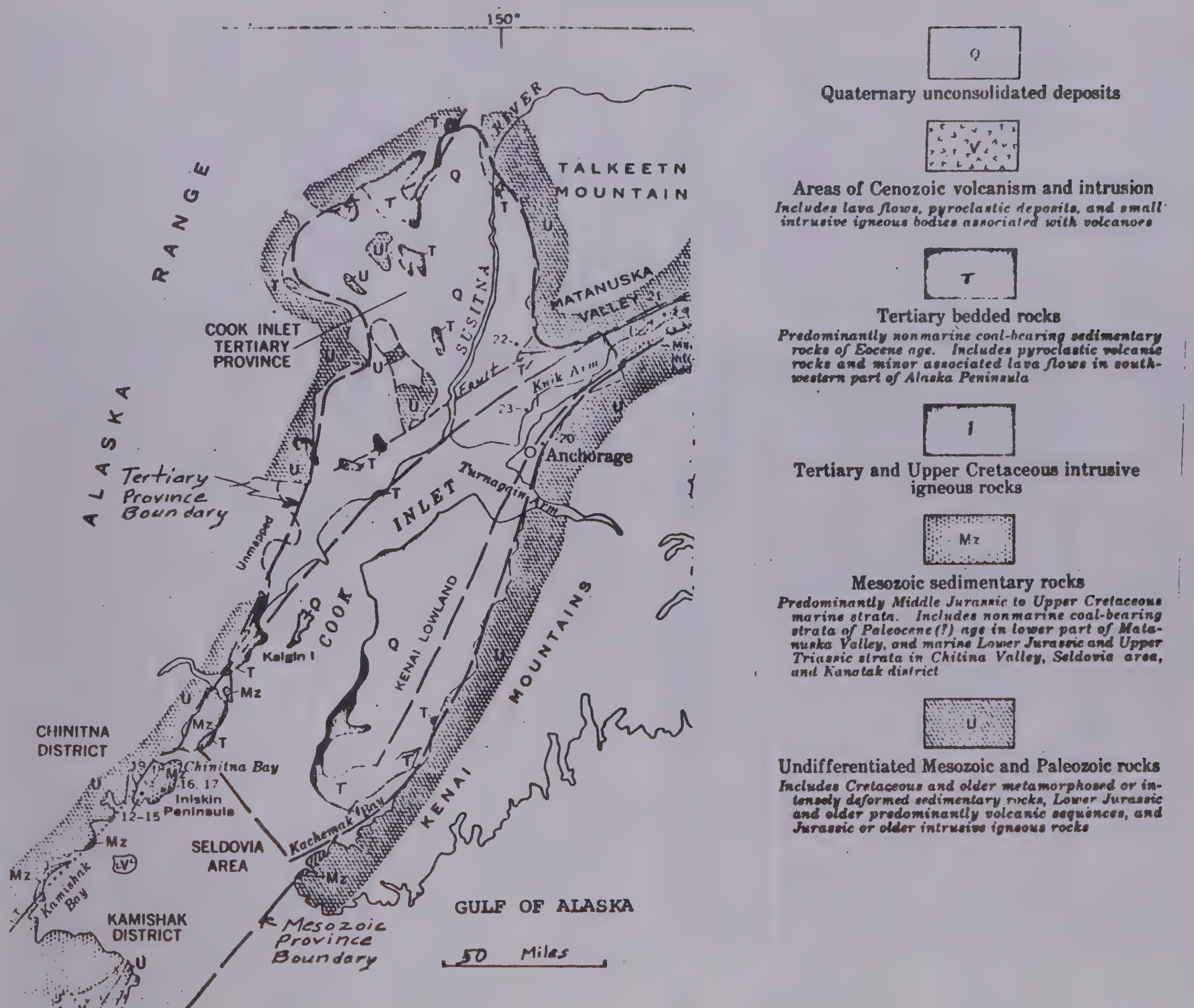


Figure 36. Geologic setting of the Cook Inlet Basin. (Source: Miller, Payne, and Gryc, 1959.)

The Jurassic section in the Iniskin-Tuxedni region includes four formations. In ascending order these are: the Talkeetna Formation, Tuxedni Group, Chinitna Formation, and Naknek Formation. Figure 37 shows the general lithologies and the members that subdivide the formations. Near the shoreline the dips of the strata range from 10° to 40° southeast and probably average 20°. The following summary is a very brief stratigraphic description; the reader is referred to Detterman and Hartsock for greater detail.

Talkeetna Formation, of Early Jurassic age, consists of 5,900 to 9,000 feet of predominantly marine volcanic breccia, agglomerate, and tuff, with interbeds of siltstone, sandstone, and argillite. A part of the sediments are of terrigenous origin. The tuffs are generally red to tan, basaltic, and indurated. Hematite, probably derived from the basalts, was reported in the Marsh Creek Breccia Member.

Tuxedni Group, of Middle and Late Jurassic age, is roughly 5,000 to 10,000 feet thick and consists mostly of fossiliferous marine sediments deposited in an epieugeosyncline. These consist of graywacke and arkosic sandstone, conglomerate, siltstone, volcanic ash, and shale. Much of the sediment appears to be reworked Tuxedni Group rocks. Some terrigenous material is present and carbonized plant remains appear in the Gaikema Sandstone Member. Specks of disseminated limonite give a rusty red-brown color to the weathered Fitz Creek Siltstone Member.

Chinitna Formation of Late Jurassic age has a maximum thickness of 2,680 feet, and consists of massive sandy siltstone. It is thought to be reworked Talkeetna and Tuxedni sediments.

Naknek Formation of Late Jurassic age is as much as 5,200 feet thick and consists of conglomerate, much arkosic sandstone, and siltstone. The Pomeroy Arkose Member is almost entirely a granitic sheetwash sediment derived from the Aleutian Range batholith. It is as much as 30 to 35 percent feldspar. Lower Jurassic sediments along the southwestern coast of Kenai Peninsula between Point Bede and Seldovia Bay consist principally of marine-deposited tuffs and volcanic agglomerates with interbedded thin beds of sandstone, shale, and limestone. The thickness of the section is probably 2,000 or 3,000 feet (Martin, Johnson, and Grant, 1915, p. 64-65).

Tertiary sediments. A few small deposits of the Tertiary Kenai Group are present on the southeastern ends of ridges near the coast. They consist of about 1,050 feet of yellowish nonmarine conglomerate, arkosic sandstone, siltstone, and some thin lenticular seams of coal.

It is difficult to judge exactly which units of the Jurassic sequence in the Iniskin-Tuxedni region are the most favorable for possible uranium deposits, but the area is relatively easy of access and could probably be evaluated reasonably economically by aerial radiometric surveys and stream-sediment sampling. The area also offers an opportunity to examine nonmarine Tertiary sediments in outcrop. The region does not seem to be well mineralized, though a small deposit of azurite and malachite was reported, and magnetite in contact metamorphic deposits occurs on Tuxedni Bay. Oil and gas under the Iniskin Peninsula are known from oil seeps and shows of oil and gas in a wildcat oil well.

Period	Epoch	Unit		Character	Thickness (feet)
Quaternary	Recent	Alluvial deposits		Gravel, sand, and silt; may include some talus and glacial outwash.	0-100±
		Littoral deposits		Boulders, gravel, sand, and silt.	0-50±
		Colluvial deposits		Rubble, talus, and landslides.	0-400±
	Pleistocene	Glacial deposits		Drift, moraine, and outwash.	0-100±
		Iliamna flows		Andesitic flows and fragmental ejecta.	80-400±
		Residual deposits [1]		Soil, rubble, and talus.	0-20±
				Angular unconformity	
Tertiary	Middle(?) to late(?)	Flows		Andesite to basalt.	0-300±
				Angular unconformity	
	Oligocene(?) and Miocene	Kenai Formation		Conglomerate, sandstone, and siltstone (terrestrial).	0-1,065
				Angular unconformity	
Jurassic	Late	Naknek Formation	Pomeroy Arkose Member	Arkosic sandstone, conglomerate, and siltstone.	850-3,300+
				Local unconformity	
			Snug Harbor Siltstone Member	Siltstone, mainly thin bedded, gray to black; interbeds of arkose.	720-860
			Lower sandstone member	Arkosic sandstone, graywacke, and siltstone. Intertonguing	0-840
			Chisik Conglomerate Member	Conglomerate, massive.	0-860
				Local unconformity	
		Chinitna Formation	Paveloff Siltstone Member	Siltstone, massive, gray-weathering; large ellipsoidal limestone concretions; sandstone unit at base.	900-1,270
			Tonnie Siltstone Member	Siltstone, massive, reddish-brown-weathering; small limestone concretions; sandstone unit at base.	820-1,310
				Local unconformity	
	Middle(?) and Late	Tuxedni Group	Bowser Formation	Sandstone, conglomerate, siltstone, and shale.	1,230-1,330
				Angular unconformity	
	Middle		Twist Creek Siltstone	Siltstone, massive, gray, rust-brown-weathering; small limestone concretions; ash beds.	0-420
				Local unconformity	
			Cynthia Falls Sandstone	Sandstone, massive; minor conglomerate and siltstone.	600-765
				Local unconformity	
			Fitz Creek Siltstone	Siltstone, massive, gray; locally arenaceous; small limestone concretions.	640-1,280
			Gaikema Sandstone	Sandstone, massive, locally conglomeratic; minor siltstone.	300-880
			Red Glacier Formation	Siltstone, thin-bedded to massive, brown; tan arkosic sandstone; black arenaceous shale.	1,980-4,540
				Regional angular unconformity	
	Early(?) and Middle	Aleutian Range batholith		Quartz diorite, quartz monzonite, granodiorite, and other granitic rocks; potassium-argon date on biotite 10 mi. west of mapped area gives 169±5 my.	
	Early	Talkeetna Formation	Horn Mountain Tuff Member	Andesitic tuff, mottled; locally contains andesite flows and arkosic sandstone.	1,800-2,8[illegible]0
			Portage Creek Agglomerate Member	Agglomerate, massive, pink; minor green volcanic breccia; locally thick andesitic flows; minor argillite.	2,250-2,850
			Marsh Creek Breccia Member	Volcanic breccia, massive, green; thick andesitic flows; minor agglomerate and argillite.	1,850-3,350
				Angular unconformity (?)	
Triassic	Late(?)	Metamorphic rocks undivided		Marble, quartzite, metachert, and argillite; locally contains basalt flows; complexly folded.	100-1,200±

[1] Range in age from Tertiary through Recent.

Figure 37. Stratigraphic units in the Iniskin-Tuxedni region, Alaska. (Source: Detterman and Hartsock, 1966.)

Tertiary Sediments of the Cook Inlet Basin

Tertiary deposition in the intermontane trough between the southern Alaska and Aleutian Ranges on the northwest and the Kenai-Chugach Mountains on the southeast reached a maximum thickness of about 26,000 feet in the central part of the basin (fig. 38). About 10,000 feet are present in the northern and southern portions (Calderwood and Fackler, 1972, p. 739; Kirschner and Lyon, 1973, fig. 11). Sediments thin to 2,000 feet or less on the north side of the Castle Mountain fault, which is a major strike-slip fault on the north side of the basin. On the north (upthrown) side of the fault, the Tertiary sediments directly overlie granitic rocks. South of the fault they overlie older Tertiary and Mesozoic bedded rocks.

Nonmarine and estuarine sediments were derived from the mountains on both sides of the trough. Coal-bearing Tertiary beds are exposed at several locations along the margins of the Cook Inlet. Large reserves of coal are contained in upper Tertiary beds on the west side of the Cook Inlet in the Beluga and Chuitna Rivers area and beneath the Kenai lowlands. Extensive exposures are present along the southwest coast of the Kenai Peninsula, where sediments are 2,000 to 3,000 feet thick.

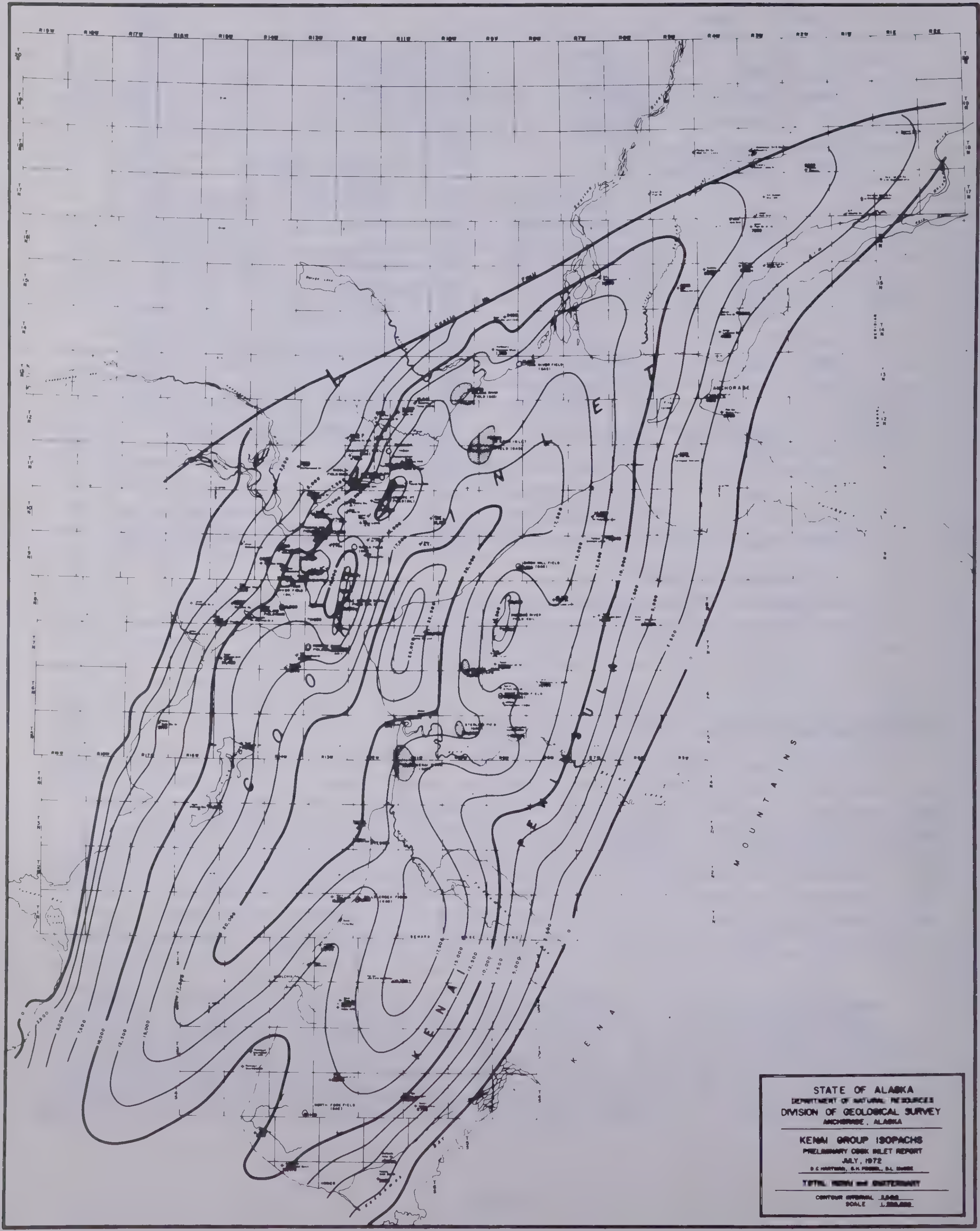


Figure 38. Kenai Group isopachs.

Kirschner and Lyon (1973, p. 401) described Tertiary deposition as being represented by two cycles: an early cycle where the depocenter was northeast of the present Cook Inlet Basin, and a late cycle when the depocenter was in the present upper Cook Inlet area. Early Tertiary sediments are present chiefly north and east of the Cook Inlet in the Matanuska Valley, but the Paleocene and Eocene Chickaloon Formation unconformably underlies the Late Tertiary sequence in the northeastern end of the Cook Inlet Basin and the Susitna lowlands (Alaska Geological Society, 1968-1969). Nearly 5,000 feet of Chickaloon Formation penetrated by the Humble Susitna unit 1 well consists of several thousand feet of garnetiferous quartzitic graywacke sandstone and micaceous and carbonaceous siltstone with interbedded coal. Chickaloon sediments seem to have been derived from a remote high-grade metamorphic terrane to the northeast of the basin. Since it is well exposed and seems to have a more favorable lithology in the Matanuska Valley, it would not be likely to be an exploration target in the Cook Inlet, where it lies at considerable depth. The Chickaloon Formation has been discussed in the section on the Matanuska Valley.

The Late Tertiary cycle is separated from the early cycle by a hiatus in Oligocene time. This cycle is represented by about 25,000 feet of estuarine and nonmarine clastic sedimentary rocks. These rocks contain the important oil and gas reservoirs in the Cook Inlet Basin fields and have received much study.

The Late Tertiary rocks in the Cook Inlet Basin were first defined by Dall and Harris (1892, p. 234-252, 327, pl. 3) who applied the name Kenai Group for the section on the southwestern part of the Kenai Peninsula. Later usage limited the name Kenai to the "Kenai Formation", which included only the coal-bearing beds. Calderwood and Fackler (1972, p. 739-754) increased the Kenai to group status again to include the entire Late Tertiary sequence in the Cook Inlet Basin. They divided the group into five formations, named in ascending order: West Foreland Formation, Hemlock Conglomerate, Tyonek Formation, Beluga Formation, and Sterling Formation (fig. 39). Calderwood and Fackler established subsurface type sections for each formation and described their lithology and electric-log characteristics. Correlations by electric logs throughout the explored parts of the basin are published on cross sections constructed by the Alaska Geological Society.

The model of the Cook Inlet Basin presented by Kirschner and Lyon (1973) indicates three phases of the Late Tertiary, created by orogenic pulses that caused unconformities between some formations and intertonguing of transgressive and regressive sandstones, which were derived from elevated regions on both sides of the basin.

The source of the West Foreland Formation, Hemlock Conglomerate, Tyonek Formation, and Beluga Formation was primarily the northwest margin of the basin at the present site of the southern Alaska Range, and they contain a high percentage of granitic material. Uplift of the Chugach Mountains provided a source for the Sterling Formation sediments, which are principally metamorphic in origin.

The following descriptions of the Kenai Group Formations apply to the subsurface of the Cook Inlet Basin and are derived from well cuttings and cores. The older formations are generally at great depth, and outcrops equivalent to any particular unit may or may not exist. The formations are described from oldest to youngest.

SYSTEM	SERIES	GROUP	FORMATION	DESCRIPTION	PAY ZONE
CENOZOIC	QUAT.		Alluvium and glacial deposits		
	TERTIARY	Kenai Group	Sterling Formation 0-11,000	Massive sandstone and conglomerate beds with occasional thin lignite bed.	o
			Beluga Formation 0'-6000'	Claystone, siltstone and thin sandstone beds, thin sub-bituminous coal beds.	o
			Tyonek Formation 4000'-7700'	Sandstone, claystone and siltstone interbeds and massive subbituminous coal beds.	o • •
			Hemlock Conglomerate 300'-900'	Sandstone and conglomerate	•
			West Foreland Formation 300'-1000'	Tuffaceous siltstone and claystone. Scattered sandstone and conglomerate beds.	•
		RESTS UNCONFORMABLY ON OLDER TERTIARY, CRETACEOUS AND JURASSIC ROCKS			

Figure 39. Nomenclature of Kenai Group. (Source: Calderwood and Fackler, 1972.)

West Foreland Formation

The West Foreland Formation of Oligocene age unconformably overlies Mesozoic strata in the central part of the basin. It appears to have been transgressively overlapped on the flanks by younger sediments. It ranges in thickness from a few hundred to more than 1,000 feet and consists of poorly sorted polymictic conglomerate, graywacke, siltstone, carbonaceous claystone with interbedded tuffs, local basalt flows, and thin coal beds. The West Foreland crops out along the foothills of the Alaska Range, where it is conglomeratic. In the central part of the basin, it is at depths between 10,000 and 16,000 feet. The West Foreland Formation has produced oil at the McArthur River field.

The carbonaceous and tuffaceous content and general stratigraphy of the West Foreland Formation seem favorable factors for the deposition of uranium, but more information is needed to assess its potential in surface or near-surface occurrences.

Hemlock Conglomerate

The Hemlock Conglomerate is the most oil productive zone in the Cook Inlet. The base is believed to be unconformable with the underlying West Foreland Formation, and its sandstones and conglomerates form a distinct mappable unit. The lithology consists of coarse conglomerate, fine- to medium-grained sandstone composed of quartz, chert, and rock fragments and some carbonaceous material; carbonaceous siltstones; and bituminous coal. The major sand development is in the west-central part of the basin. It is up to 1,030 feet thick, but like the West Foreland, generally lies at considerable depths and apparently is absent along basin margins.

Tyonek Formation

The Tyonek Formation conformably overlies the Hemlock Conglomerate and has a total thickness of up to 7,650 feet. The Tyonek is characterized by massively bedded sandstone and thick coal beds. Several local unconformaties within the sequence have been observed in outcrops. The dominant lithologies are fine- to coarse-grained sandstone, which is often conglomeratic and bentonitic. Beds of hard, gray, micaceous siltstone, silty shale, and coal occur throughout the section. Garnet in the heavy-mineral suite suggests a high-grade metamorphic source area, similar to that for the Chickaloon Formation. Maximum sediment development is in the west-central part of the Cook Inlet. Oil and gas are produced from the formation at several fields.

Beluga Formation

The Beluga Formation overlies the Tyonek Formation with apparent unconformity. It is between 500 and 4,150 feet thick in wells drilled in the basin and consists of intercalated beds of sandstone, claystone, siltstone, and lignitic to subbituminous coal. It is slightly more restricted in area than the underlying formations and is distinguished from the Tyonek by a lack of massive sandstone beds and thick coal seams. The predominant source area is thought to be the highlands in the Kenai Peninsula. The sandstones are fine to medium grained, silty, carbonaceous, and have a clayey matrix. The claystones are gray, bentonitic, carbonaceous, and lignitic. Coal beds range from thin stringers to seams 12 feet thick.

Sterling Formation

The Sterling Formation lies disconformably on the Beluga Formation and in type section consists of about 4,500 feet of massive sandstones, conglomerates, and interbedded siltstones, with thin coal beds throughout. Its upper contact is at 1,050 feet, where it is overlain by Pleistocene gravels, though the top is difficult to pick because it is similar to the Quaternary deposits. The sandstones are fine to medium grained, loosely cemented, quartzose, carbonaceous, and bentonitic. Discontinuous outcrops of the Sterling Formation are observable for several miles in bluffs along the western margin of the Kenai Peninsula between Clam Gulch and southwestward to and beyond Ninilchik.

While the Sterling Formation may be the most accessible portion of the Tertiary in the basin, it may be less favorable for uranium than others, since its source is believed to be the metamorphic rocks of the Chugach Range (in contrast to the older sediments, which had the granitic rocks in the southern part of the Alaska Range as their source).

The most extensive outcrops of the Kenai Group are along the southeast shores of Cook Inlet and Kachemak Bay, where exposed thicknesses are believed to be at least 5,000 feet. North of Anchor Point, bluffs composed of Kenai sediments are between 50 and 300 feet high. They are also visible in a number of short canyons near the coasts. At least 30 coal beds ranging from 3 feet to 7 feet are widely distributed throughout the Kenai Group.

The following description of the character of the Kenai Group in the Homer district of the Kenai Peninsula is taken from Barnes and Cobb (1959, p. 224):

> *The Kenai formation consists of moderately indurated sand, silt, and clay in generally thin and intergrading beds and lenses, interbedded with a few thin lenses of fine conglomerate and many beds of subbituminous and lignitic coal ranging from a few inches to 7 feet in thickness. Thin layers of volcanic ash were found as partings in several coal beds near the head of Kachemak Bay (pls. 26 and 27). Ferruginous masses in thick sandstone beds, and ironstone concretions, in distinct bands and as scattered nodules, are common throughout the formation except to the north of Ninilchik, where they are relatively scarce. The resistant masses of sandstone are particularly noticeable on some sections of beach where they have accumulated as irregular-shaped boulders as the wave-cut bluffs receded.*

On the north side of the Cook Inlet, the Kenai Group is exposed between the village of Tyonek, on the coast, and Capps Glacier and Beluga Lake, to the north. Exposures are almost continuous along the Chuitna River north to the Castle Mountain fault. North of the fault, the Kenai crops out over several broad areas. This area includes the Beluga coal field, which is presently under study by a number of firms interested in the coal reserves. The Kenai beds are generally flat lying except near the mountain front and near the Castle Mountain fault. A general description of the Kenai in this region is taken from Barnes (1966, p. C9):

> *The Kenai Formation in the Beluga-Yentna region consists of intergrading and generally lenticular layers of clastic rocks, ranging from claystone to coarse conglomerate, that generally are light gray to buff but locally are dark gray, particularly near coal beds. The rocks generally are slightly to moderately indurated but include a few resistant beds of cal-*

careous siltstone. Concretions and irregular masses cemented by iron carbonate are locally present, particularly in the thicker sandstone beds. Beds of subbituminous coal and lignite as much as 50 feet thick are abundant in certain areas, and streaks and lenses of carbonized plant material are common throughout the formation. The abundant plant material, irregular bedding, and total absence of marine fauna indicate that the formation is of nonmarine origin.

Detailed logs of numerous drill holes which reached depths up to 366 feet at the Beluga River coal field have been published by the U.S. Bureau of Mines (Warfield, 1963).

A few miles northwest of Palmer townsite, nonmarine coal-bearing Cretaceous or Tertiary sediments crop out in the Little Susitna district. This area is a westward extension of the Matanuska Valley deposits. The Little Susitna district of coal-bearing rocks covers an area 1 to 2 miles wide that extends 22 miles in an east-west trend. The westernmost end of the belt projects into the Susitna lowland. Total thickness of the sequence is at least 1,200 feet near Houston (Barnes and Sokol, 1959, p. 125). A 600-foot sequence of moderately indurated pebble conglomerate and sandstone is exposed in the southern part of the Little Susitna Canyon, but its relation to the coal-bearing rocks is not established. The conglomerate dips 35^{o} to the south and appears to underlie the coal-bearing section. The coal-bearing formation is described by Barnes and Sokol (1959, plate 7) as poorly indurated, fine to coarse pebbly sandstone, claystone, and coal. These are mostly covered by glacial deposits and terrace gravels. A detailed description does not seem to be available.

Brief descriptions of the Tertiary outcrops on the north side of the Cook Inlet and in the Susitna lowlands were made by Capps (1935, p. 60-65), who made a reconnaissance study of the region. About 1,000 feet of Tertiary beds near Tyonek were described as friable sandstone, conglomerate, shale, and lignitic coal, striking N 10^{o}-15^{o} E and dipping 15^{o}-60^{o} SE.

Structure

The N 30^{o} E trend of contacts, folds, and faults in the Cook Inlet Basin parallel the Matanuska geosyncline. The basin is an asymmetric intermontane graben or half graben with a steeper, more complex northwest flank. Mesozoic rocks crop out on the east and west edges and dip toward the structural axis. The structural basin was formed in early Middle Jurassic time and has experienced strong marginal uplift throughout its history. Tertiary nonmarine sediments have been deformed into a series of long, narrow, echelon anticlines, which are oil and gas productive. The Tertiary formations are thinner and less deformed along the edges of the basin.

The Castle Mountain fault forms the northern boundary of the geosyncline and may have up to 10,000 feet of vertical displacement (Grantz, Sietz, and Andreason, 1963, p. 123). Transcurrent faulting is present as part of the Castle Mountain fault system, and dip-slip thrust faulting is present in some of the high-relief anticlines in the basin. Normal faults are also common in the anticlines, though they generally die out before reaching the surface. The large Bruin Bay fault borders the southern half of the basin on the northwestern side. The basin is nearly surrounded by mobile zones, and the frequency and magnitude of earthquakes in the region testify that they are still active.

Igneous Rocks

The igneous rocks of the Cook Inlet region can be grouped into three areas: the Aleutian Range batholith on the northwestern margin of the basin; the Talkeetna batholith at the northeastern end; and the Kenai-Chugach Mountains on the southeast side.

The Aleutian Range batholith (Naknek Lake batholith of Burke, 1965) is the largest igneous complex in the state, possibly excepting the Coast Range batholith in southeastern Alaska. It extends about 200 miles in a northeasterly direction on the north side of the Cook Inlet and is between 40 and 80 miles wide; the widest part is at the northern end, where it merges with the southern Alaska Range. The Aleutian Range batholith forms the backbone of the Chigmit Mountains in the Cook Inlet region. Much of the pluton is unmapped or covered only by reconnaissance surveys. Granitic stocks, satellitic to the batholith, crop out near the Cook Inlet shore; several stocks are present between the Susitna and Beluga Rivers.

Work in the Iliamna area has shown the batholith to be a composite body consisting of hornblende quartz diorite, hornblende-biotite quartz diorite, biotite-hornblende quartz diorite, and biotite quartz diorite. Phases of granodiorite, quartz monzonite, and granite are present locally (Detterman and Reed, 1964; 1965, p. D16). Small bodies of hornblende gabbro and hornblendite that may be early basic stages of the batholith occur as inclusions in the more silicic rocks. The K-Ar determinations indicate an age of 170 m.y. (Early Jurassic) for emplacement of the pluton. Reed and Lanphere (1972) have compiled a generalized geologic map of the Alaska Aleutian Range batholith showing the K-Ar ages of the plutonic rocks over a wide area.

Little information is available on the igneous rocks of the Kenai and Chugach Mountains in the Cook Inlet region. A general statement on the intrusives is taken from Martin and others (1915, p. 36):

> *Intrusive rocks are abundant in various parts of Kenai Peninsula. They are most numerous in the slates and graywackes, but a few were observed in the Triassic and Jurassic rocks. There are none in the Tertiary beds.*
>
> *The most extensive of the intrusive rocks are the granitic masses, which are greatest and most abundant in the slates on the southern and eastern coasts. The largest masses occur in the vicinity of Aialik Bay and Pye Islands. An unmapped area of granite occurs at the headwaters of Benjamin Creek, near Skilak Lake.*
>
> *Small acidic dikes are numerous in all the slaty rocks along the southern shore of the peninsula. They also occur in the slate and graywacke between Kenai Lake and Turnagain Arm and in the Crow Creek district. Small dikes of several kinds cut the slates and the Mesozoic rocks on the south shore of Kachemak Bay.*
>
> *Masses of peridotite intrude the slate and graywacke at Red Mountain, southeast of Seldovia, and on the north shore of Port Chatham, and diabase and gabbro occur near Point Bede and Grewingk Glacier.*

Igneous rocks of the central and northern parts of the Kenai Peninsula are divided into two types: (1) fine-grained quartz diorite stocks and bosses, and

(2) fine-grained dike rocks related to the quartz diorite. Ore deposits accompanied emplacement of the plutons.

Granite is exposed for several miles south of Resurrection Bay on the southeast side of the bay. Gabbro and diabase occur in the vicinity of Dog Salmon Bay. At Red Mountain, southeast of Seldovia, and at Claim Point, on the north side of Port Chatham, are masses of peridotite. Chromite deposits are present at Red Mountain. Small dikes of several kinds of rock deposits are south of Kachemak Bay: diabase rhyolite porphyry and gabbro cut graywacke and slate of Mesozoic or Paleozoic age. Jurassic volcanic tuffs that are partly nonmarine are at least 1,000 feet thick and possibly much thicker along the southwestern end of Kenai Peninsula.

The rocks of the Aleutian Range batholith complex become progressively more acidic with decreasing age. The younger intrusives are most abundant in the northern portion, where the Chigmit Mountains merge with the southern Alaska Range. Reed and Lanphere (1972) have shown that the more acidic Cretaceous and Tertiary differentiates are mineralized, whereas the older Jurassic rocks are more basic and display little evidence of mineralization. This indicates that the most favorable areas of the complex for uranium are the youngest intrusive bodies, which are adjacent to the upper Cook Inlet and the Susitna lowland (see map of Reed and Lanphere, 1972).

The Talkeetna batholith, which forms the core of the Talkeetna Mountains, is a very large complex consisting dominantly of quartz diorite, but also contains diorite, granodiorite, and quartz monzonite. In some parts it is highly foliated. Exposures in the Kotsina Creek area on the eastern part of the Talkeetna Mountains have been sampled for age dating. Grantz and others (1963, p. B56) found that K-Ar ages of the pluton were 160-165 m.y., Middle to Late Jurassic. Tertiary and Cretaceous intrusives form the western part of the complex (Csejtey, 1974). Although much of the Talkeetna Mountains have not been mapped, prospecting and reconnaissance surveys have found the region to be mineralized. The distribution of the igneous rocks is indicated by a compilation by Capps (1940, plates 1 and 2).

About 20 miles east of Anchorage on the southwest flank of the Chugach Mountains, water-lain greenstone and andesite tuffs and lavas with minor amounts of interbedded Mesozoic sediments cover about 200 square miles (Capps, 1916, plate 8 and pp. 161-165). The tuffs predominate and in part are actually agglomerates, but generally are lithified to the extent that they resemble graywacke. The series is probably at least 5,000 feet thick.

Economic Geology

The economic geology of the Cook Inlet is largely concerned with petroleum. The discovery of oil at the Swanson River field on the Kenai lowland in 1957 led to the development of 21 oil and gas fields in the district. Production is entirely from the Tertiary Kenai Group. The Hemlock formation is the most important producing zone, but production is obtained from several sections within the Kenai Group. The reserves were estimated (Kirschner and Lyon, 1973, p. 396) to be 1.5 billion barrels of recoverable oil and 5 trillion cubic feet of gas. The Inlet has played an important part in the economy of Alaska.

Coal in the Tertiary rocks is also an important resource in the Cook Inlet region. The Beluga coal field, about 53 miles west of Anchorage, is presently being

investigated by a number of firms. Barnes (1967) estimated that the reserves of the Susitna area approach 2.4 billion short tons of subbituminous and lignite coals, mostly confined to a 400-square-mile area in the Beluga-Chuitna River drainage. Several coal beds exceed 50 feet in thickness. Overburden ranges in depth from a few feet to 225 feet. The Beluga-Chuitna coal is believed to be a continuation of the Tertiary Kenai beds exposed in the west side of the Kenai Peninsula. The problem of correlating Tertiary outcrops with the subsurface in the Cook Inlet is referred to by McGee (1973, p. 4):

> *Direct correlations between the coal-bearing Middle Kenai formation in the Beluga-Chuitna area and the Kenai formation in drilled wells in the Cook Inlet have not been made. However, based on the occurrence of thick coals in the upper part of the Tyonek formation, a logical correlation would indicate that the Middle Kenai coal-bearing beds of the Beluga-Chuitna area are equivalent to the upper part of the Tyonek formation where thick coals are seen in drilled wells throughout the Cook Inlet Basin.*

Tertiary coal is believed to underlie a large part of the Kenai lowlands, but because most of the area is covered by several hundred feet of glacial and alluvial deposits, no reserve estimate is available. In the Homer district, which includes the Kenai lowland south of Tustumena Lake, at least 30 coal beds ranging from 3 to 7 feet thick are exposed in coastal bluffs of the lower Cook Inlet and Kachemak Bay.

The Cook Inlet Region includes several mining districts with a variety of ores. The distribution of the deposits and their references have been compiled by Cobb (1972a-d), Detterman and Cobb (1972), and Clark and Cobb (1972). The following summaries are taken largely from Berg and Cobb (1967).

Anchorage District

The Anchorage mining district is bounded on the south by Turnagain Arm, on the west and north by Knik Arm, and on the east by the divide between Cook Inlet and Prince William Sound. The district is underlain by Mesozoic metasediments and Tertiary basalts and tuffs. Felsic dikes cut the slates and graywackes. Capps (1916, p. 181-194) has described the ore deposits. Lodes containing gold, silver, copper, lead, zinc, molybdenum, and chromite are present, but they have yielded only a small tonnage of ore, mostly before World War II. Placer gold deposits were worked in the Glacier Creek drainage on the north side of Turnagain Arm. A small tonnage of low-grade chromite in dunite is present along the Anchorage-Palmer highway a few miles east of the head of Knik Arm. The ultrabasic rocks have intruded a complex of andesite and tuffs that have been altered to greenstone (Bjorklund and Wright, 1948).

Willow Creek Mining District

One of the most important gold lode mining districts in Alaska is the Willow Creek district, located in the southwestern part of the Talkeetna Mountains, near the mouth of the Matanuska Valley and 12-16 miles northwest of Palmer. The district covers 50 square miles and extends nearly 15 miles from east to west. Gold production to 1950 was nearly $18 million, produced from numerous small mines clustered in the district. None of the mines has produced over $1 million and

most have been developed to only shallow depths. Cobb (1972) listed 37 lode deposits and 13 placer mines. The following information on the ore deposits is taken from Ray (1954):

> *Productive gold quartz veins occupy north-south striking shear zones, largely in quartz diorite, near the southwestern edge of the Talkeetna batholith. Dikes of lamprophyre, diabase, aplite, and pegmatite are common. The ore is principally free-milling gold in quartz veins which contain minor amounts of pyrite, arsenopyrite, sphalerite, chalcopyrite, tetrahedrite, galena, and scheelite. Other sets of veins which are not commercial contain chalcopyrite, molybdenite, and stibnite. Hydrothermal alteration of the wall rock is intense within a few inches of the productive veins. Small pegmatite dikes in the Willow Creek district are slightly radioactive due to small amounts of <u>uraninite</u>, cyrtolite, allanite, and <u>thorite</u> (Moxham and Nelson, 1952, p. 7-10).*

Tuxedni Bay Magnetite Deposits

Tuxedni Bay is an embayment on the northwest side of the Cook Inlet, about 115 miles southwest of Anchorage. Magnetite deposits are located on an island near the head of the bay. Magnetite, which is probably related to nearby quartz diorite batholith, occurs in contact-metamorphosed Triassic and Jurassic volcanics and sedimentary rocks. Magnetite and garnet have replaced marble-hornfels. The eastern deposit consists of low-grade disseminated magnetite in hornfels. The western deposit, which may contain as much as 75 percent magnetite, is 35 feet thick where exposed in a sea cliff and crops out for 55 feet along strike (Grantz, 1956). A small amount of copper is present.

Aleutian Range (Southern Redoubt Mining District)

Scattered lode deposits containing copper, gold, silver, lead, molybdenum, zinc, and iron are present in the Aleutian Range west of Kamishak Bay in the lower Cook Inlet region. Detterman and Cobb (1972) listed 25 lode deposits and one placer gold deposit in this part of the Iliamna quadrangle. Eight of the lodes lie on the western side of the range; the rest are in drainages adjacent to the Cook Inlet. Bedrock consists of Triassic andesite lava, Jurassic and Cretaceous sandstone and shale, Tertiary coal-bearing sediments, and Quaternary flows and tuffs from active volcanoes in the area.

The only deposit with recorded production is the McNeil gold lode, located about 22 miles southwest of Kamishak. Twelve tons of ore assaying $2.50 a ton in gold, 15 ounces per ton of silver, and 17.55 percent copper was shipped early in the century (Berg and Cobb, 1967, p. 22). The general area may have a good potential for copper and magnetite.

Kenai Peninsula

East of the Kenai lowlands that border the Cook Inlet rise the rugged Kenai Mountains, which contain numerous old mines and prospects. The mountains average about 4,000 feet above sea level and are composed of slightly metamorphosed and complexly faulted Mesozoic sediments. These have been intruded by dikes, sills, and stocks that range in composition from granite to peridotite (Berg and Cobb,

1967, p. 73-82). The main areas of felsic and intermediate rocks are on the eastern side of the peninsula and do not drain into Cook Inlet. Although the Kenai peninsula is one of the oldest producing mining regions in Alaska, the total production is relatively small, estimated to have been approximately $3,302,000 to 1930 (Tuck, 1933, p. 488).

Lodes in the southern half of the Kenai Peninsula (Homer district) have been worked for gold, silver, and a small amount of chromite. The veins are in graywacke and slate near quartz diorite plutons and contain gold, silver, copper, pyrite, arsenopyrite, chalcopyrite, galena, tetrahedrite, covelite, and chalcocite. Production has been almost entirely for the gold values.

Two groups of chromite deposits are located in ultramafic plutons near the southern tip of the peninsula: one near Clam Point, and one near the top of Red Mountain. A small amount of ore averaging 42-45 percent Cr_2O_3 has been mined during intervals between 1917 and 1957.

A mineralized belt extends north-south across the northern part of Kenai Peninsula between Turnagain Arm and Blying Sound. It includes the Hope and Seward districts. Only gold and silver have been produced from the area, but some lead, zinc, molybdenum, and antimony are present. Placer mining was conducted for many years at numerous sites in the northern part of the peninsula. Nuggets of native silver and native copper have been found in placers of several creeks. Additional descriptions of ore deposits in the northern part of the Seward Peninsula are in a report on the Moose Pass—Hope Creek district by Tuck (1933). Most deposits are associated with persistent north-striking felsic dikes along the west side of Canyon and Sixmile Creeks south of Sunrise.

Radioactivity Investigations

Reconnaissance for radioactivity in the Anchorage district produced samples of placer concentrates from five streams. The eU values were 0.000 to 0.002 percent (Moxham and Nelson, 1952, p. 5).

Radioactive studies by Moxham and Nelson (1952, p. 7-10) in the Willow Creek mining district followed the finding of radioactive pegmatite float containing uraninite and thorite. Representative channel samples from 11 pegmatites from the Fishhook Creek—Archangel Creek area ranged from 0.002 to 0.007 percent eU and averaged 0.004 percent. The heavy fractions of the samples ranged from 0.016 to 2.93 percent eU and averaged 0.332 percent. Radioactive minerals identified were uraninite, thorite, cyrtolite, and allanite. The authors concluded the radioactive pegmatites of the Willow Creek district could not be considered a commercial source of uranium.

Chisik Island, near the west shore of Cook Inlet at the mouth of Tuxedni Bay, was traversed in an attempt to locate the source of an anomaly detected from the air. None was located on the ground and it was concluded that the earlier anomaly was due to the mass effect of granitic material in the Chisik Conglomerate Member of the Naknek Formation (Freeman, 1963, p. 43).

Investigations for radioactivity deposits in the Iliamna Lake—Lake Clark region were conducted by Moxham and Nelson (1952, p. 1-4). Sampling was done on the west side of the Aleutian Range in areas not draining into Cook Inlet, but the close proximity to the inlet justifies the inclusion of the results here. Examinations were made of two silver-lead occurrences, five copper deposits, a molybdenum prospect, and numerous concentrates from numerous stream gravels. Also, about 310

miles of traversing was done with portable instruments. The maximum eU of any material tested did not exceed 0.009 percent. Radioactivity of concentrates collected from the east shore of Lake Clark (0.007 percent eU) may be due to traces of a sooty, black, uranium mineral (Wedow, 1956, p. 33).

A curious report suggests the possibility of sedimentary uranium occurrences in the Nikolai Creek area, northwest of Tyonek village. Samples of metatyuyamunite-bearing limestone submitted by H.N. Fowler, a prospector from Anchorage, contained as much as 0.92 percent uranium (Matzko and Bates, 1955, p. 7-10; Wedow, 1956, p. 86-87). According to reports, an Indian named Chickalusian from Tyonek found the samples in 1949 on the north side of the valley of a left-limit tributary of Nikolai Creek, 16 miles northwest of Tyonek. The Indian, Fowler, and Wedow of the USGS failed in an attempt to reach the location in 1952. Another attempt was made in 1953 by Wedow and Bates of the USGS and Fowler, but they also failed to reach the reported site of the samples. A helicopter was not available during these attempts and no abnormal radioactivity was detected in the general area.

Chickalusian's description of the outcrop from which the samples were reportedly taken indicated it to be approximately 50 feet long and 10 feet thick with lenses of "yellow rock" up to 3 inches thick between thin beds of limestone. Exposures along the northeast side of Nikolai Creek, according to Capps (1935, p. 62 and plate 1) and Barnes (1966, plate 1), consist of Eocene sandstone, shale, conglomerate, clay, tuffs, and coal. Tertiary beds crop out in an 25-square-mile area northeast of the head of Nikolai Creek and on the southeast flanks of Mt. Spur. The location map on page 8 of the report by Matzko and Bates (1955) indicates three points northwest of the head of Nikolai Creek where "carnotite" has reportedly been found, but they all remain unverified. Limestone is not known to be present in the area, but detailed mapping has not been done.

Discussion

Suggested areas for uranium exploration in the Cook Inlet region are:

(1) Nonmarine Tertiary sediments underlying the Kenai lowlands.

(2) Nonmarine Tertiary sediments underlying the area north of Tyonek in the Beluga-Chuitna district.

(3) Jurassic sediments in the Iniskin-Tuxdeni region.

(4) Late-stage granitic rocks in the northern Aleutian Range batholith.

(5) Tributaries at the northeastern end of Lake Clark for the source of a "sooty, black, uranium-bearing mineral."

(6) The area north of the head of Nikolai Creek for possible occurrences of metatyuyamunite-bearing limestone.

A thick nonmarine Tertiary section is present over a broad area in the Cook Inlet region. The sediments offshore are beneath considerable depths of water and extend to great depths below the bottom of the inlet and are deformed into sharp anticlines. The beds exposed along the coast of the Kenai Peninsula and underlying the Kenai lowlands and on the northwestern side of the Cook Inlet,

however, are generally flat lying and at shallow depths. These Tertiary sediments contain arkosic sandstones and tuffaceous and carbonaceous materials beneath lowlands that are easily accessible for exploration and drilling.

It is suggested that the Jurassic arkosic sandstones and conglomerates in the Iniskin-Tuxdeni region deserve to be examined for possible sedimentary uranium. Small areas of Tertiary nonmarine sediments are also exposed in this area.

Granitic rocks of the Aleutian Range Batholith, especially small satellitic stocks, may be favorable uranium source rocks or hosts for vein-type uranium deposits. The rocks of the batholith complex become more alkalic and more highly mineralized with decreasing ages. The late phases are more common in the northern end of the batholith. Granitic rocks and a thick section of volcanic tuffs in the Talkeetna Mountains could also be sources for uranium within the sediments in the lowlands.

Reconnaissance investigations for radioactivity at mines and prospects in the Cook Inlet region and on the Kenai Peninsula generally have not been promising. The highest assay (0.007 percent eU) was from pegmatitic material in the Willow Creek mining district. However, traces of a black, sooty, uranium-bearing mineral found on the northern end of Lake Clark may be indicative of more extensive deposits, and the Nikolai Creek area northwest of Tyonek should be investigated by helicopter-supported radiometric and geochemical surveys to determine the validity of reported occurrences of metatyuyamunite-bearing limestone.

SUSITNA LOWLAND

The Susitna Lowland is bounded on the north and northwest by the Alaska Range foothills, on the east by the Talkeetna Mountains, on the south by the Castle Mountain fault, and on the southwest by the northern part of the Aleutian Range (figs. 40, 41). It is mostly covered by the Talkeetna and Tyonek 1:250,000 topographic sheets. The lowland is formed in the broad, glaciated valleys on the Susitna River and its tributaries, especially the Yentna River. Some authors refer to the region as the Susitna Basin, while others call it the Susitna Lowlands, which seems to the presently accepted name. The lowland occupies approximately 6,000 square miles. It is 60 miles wide at the lower end near Cook Inlet; it narrows and terminates about 80 miles to the north in the foothills of the Alaska Range. Although the Susitna Lowland is sometimes considered to be an extension of the Cook Inlet Basin, the two areas are separated in the subsurface by the large Castle Mountain fault system, and the writer believes that they should be viewed as two different provinces for uranium investigations. The Susitna Lowland on the upthrown side of the Castle Mountain fault is relatively shallow and only slightly deformed compared to the central part of the Cook Inlet Basin (Barnes, 1966, plate 5). Tertiary sediments of the Cook Inlet lap over into the Susitna Lowland where they are at least 2,000 feet thick.

Mesozoic and Tertiary intrusive rocks and Mesozoic metasediments form extensive bedrock exposures in the rugged Alaska Range and Talkeetna Mountains. Large glaciers extend down the southern flanks of the Alaska Range and their meltwaters drain into the Susitna Lowland. Mt. McKinley National Park, where Mt. McKinley reaches an altitude of 20,300 feet, occupies a large portion of the range in this region. The Susitna Lowland is generally covered by Quaternary gravels and alluvium and glacial material, though they are not so thick as to completely obscure underlying Tertiary sediments which are exposed along some stream channels

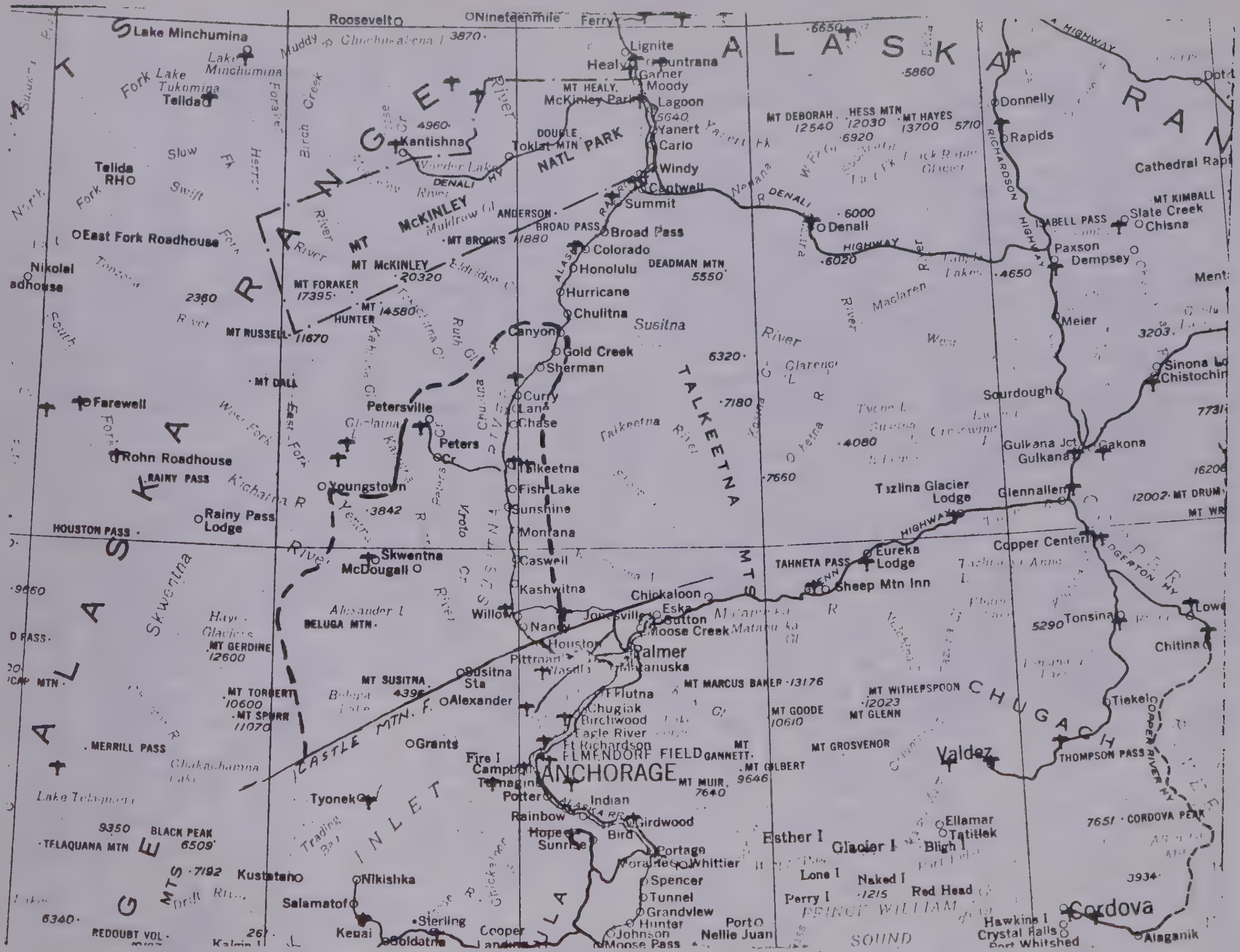


Figure 40. Index map showing location of the Susitna Lowland. (Base from USGS Map E, 1:250,000 scale.)

Figure 41. Relief map showing location of Susitna Lowland. (Base from USGS Map E, 1:250,000 scale.)

and in outcrops in marginal areas. Much of the lowland, especially the southern portion, has a low relief and is covered by bogs, marshes, and lakes. The elevations are generally only a few hundred feet, but the surface rises to as much as 2,000 feet near the front of the Alaska Range, and a few isolated mountains interrupt the lowland with altitudes from several hundred to a few thousand feet (Barnes, 1966, plate I). The Susitna River almost encircles the Talkeetna Mountains at the west, north, and northeast. The headwaters of the river originate in the central Alaska Range and the northeastern part of the Talkeetna Mountains. The Copper River Basin at one time may have drained to the northwest through the Susitna River valley (Capps, 1940, p. 27).

The average annual precipitation at the Talkeetna airport is 28 inches, and the average annual temperature is 33° F. The central lowland area is free of permafrost, but the margins contain isolated masses of it. Vegetation consists of intermixed forest, muskeg, and tundra shrub.

The newly completed Anchorage-Fairbanks highway and the Alaska Railroad extend along the eastern edge of the lowland on the east side of the Susitna River. Landing strips are located at several townsites along the highway and at some of the old mining camps in the western part of the lowland, especially on Cache Creek and near Fairview Mountain. The FAA airport at Skwentna has a 3,000-foot landing strip. Float planes also can land at many of the lakes. In general, the Susitna Lowland is easily accessible by aircraft and possesses some features that seem promising for the occurrence sedimentary-type uranium deposits in the Tertiary sediments.

Sedimentary Rocks

Source rocks for the sediments in the Susitna Lowlands include a great variety of metasedimentary, volcanic, and intrusive rocks distributed over a very large area. Information on the pre-Tertiary sediments in the region is meager, and in the bordering mountains large areas are either unmapped or have been mapped only by reconnaissance surveys. The most complete geologic map of the total area is the 1:250,000 scale map by Capps (1940, plate 2). Most of the published data on the lowlands are concerned with the Tertiary coal resources. A large portion of the Susitna Lowland is covered by what Barnes (1966) refers to as the Beluga-Yentna region. Barnes' report on the region pertains mostly to the coal reserves but includes a brief summary of the known stratigraphy.

Slate and graywacke deposited in the Alaska Range geosyncline crop out in the northwest part of the lowland, and Mesozoic and older volcanic, plutonic, and metamorphic rocks of the Talkeetna geanticline are thought to be absent from the Susitna Lowland north of the Castle Mountain fault.

As a result of the oil discoveries in the Cook Inlet, studies of parts of the Susitna Lowland have been made by oil companies, but the results are largely unpublished. A cross section of the Susitna Lowland compiled by Bennison (1974, section A-A') shows sections of Pennsylvanian and Permian metamorphic rocks and Tertiary-Cretaceous intrusives underlying the Tertiary sedimentary basin (fig. 42). The source of the data for this section may be from petroleum company files. A single exploration well, Union Texas Petroleum No. 1 Pure Kahiltna River State, has been drilled in the Susitna Lowland. The Talkeetna Mountains are composed mostly of intrusive rocks along the eastern edge of the Susitna Lowland but contain a belt of Mesozoic metasediments along the northwestern edge of the mountains. The central and southern parts of the Alaska Range contain Paleozoic and Mesozoic metasediments

and a variety of intrusive and volcanic rocks. The Lowlands themselves are underlain by coal-bearing nonmarine Tertiary sediments and are at least 2,000 feet thick and may be much thicker.

The oldest rocks exposed in the foothills bordering the Susitna Lowland are probably the Devonian and Carboniferous rocks on the west side of the West Fork of the Chulitna River in the Chulitna-Yentna belt (Ross, 1933; Hawley and Clark, 1973). In this belt are Devonian calcareous sediments and an assemblage of volcanic breccia, tuffs, and lava with minor interbedded argillite, limestone, chert, and conglomerate which may be Permian in age.

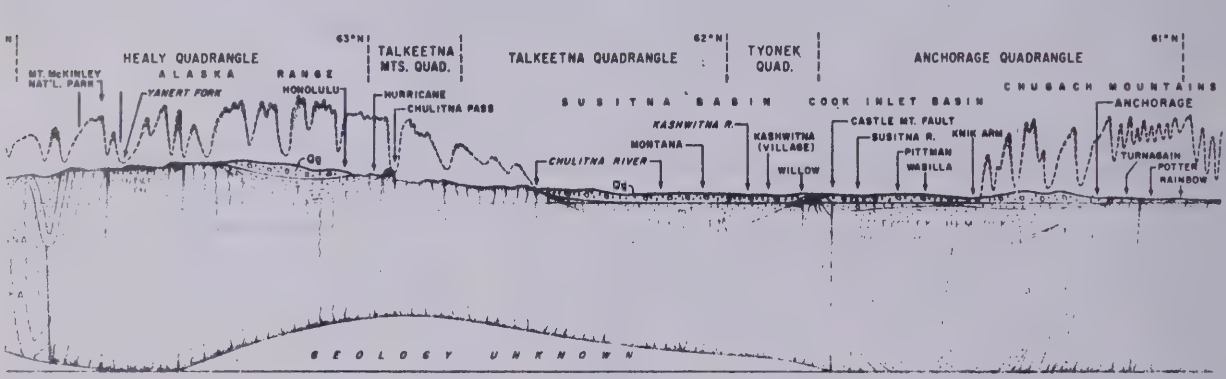


Figure 42. North-south cross section of the Susitna Lowland. (Source: Geological Highway Map of Alaska and Hawaii, pub. by Am. Assoc. of Petroleum Geologists.)

The upper Chulitna district on the southeast flank of the Alaska Range, about 130 miles north of Anchorage, has received considerable study. The structure and rock complexes here offer opportunities for unraveling the history of the region. Also, the district is highly mineralized and has economic potentials for several metals. Table 4 summarizes the lithology.

Part of the rocks in the Upper Chulitna district include an assemblage of ultramafic rocks, chert, and basalt that has been interpreted as an ophiolite assemblage that was incorporated into the continent (Clark and others, 1972, p. C95-C101). The assemblage, thought to be Permian in age, lies in a narrow northeast-trending belt about 20 miles long.

Mississippian to Permian metavolcanics and metavolcanic clastic rocks which include some beds of marble are present along the Talkeetna River in the central Talkeetna Mountains near the eastern border of the Susitna Lowland. In the large bend in the upper part of the Susitna River where its course changes from north to east, there are isolated hills of probable pre-Carboniferous age. Chapin (1918, p. 23-25) described the rocks as differing widely in composition but being made up mostly of greenstone and schist with local beds of limestone, slate, and quartzose rocks and dioritic and diabasic intrusives. Farther east up the Susitna River, mildly metamorphosed schistose metavolcanics and metasediments have been mapped by Smith (1973) in a 40-mile-long northeast-trending belt. The belt crosses the Susitna River in the northern part of the Talkeetna Mountains.

Table 4. Comparison of lithologic assemblages and depositional environments in the eastern and west-central Alaska Range.

Age	Lithologic assemblages: Upper Chulitna district of the west-central Alaska Range	Lithologic assemblages: Eastern Alaska Range (from Richter and Jones, 1972)	Depositional environment
Tertiary and Quaternary.	Arenaceous and carbonaceous sedimentary rocks, plutonic rocks.	Wrangell Lava.	Continental.
Late Cretaceous . . .	?	Nonmarine sedimentary deposits.	Continental.
Early Cretaceous . .	?	Andesitic volcanic, volcaniclastic, and minor marine sedimentary rocks.	Marine, associated volcanism in eastern Alaska Range.
Late Jurassic and Early Cretaceous.	Argillite, graywacke, and conglomerate.	Argillite and flyschlike clastic sedimentary rocks.	Marine foreland or successor basin.
Early and Middle Jurassic.	?	. . . .	
Middle and Late Triassic.	Interlayered limestone and basalt. Limestone and calcareous siltstone.	Thin limestone beds interlayered with marine shale and cherty argillite. Massive micritic limestone. Subaerial flood basalts (submarine flows in Canada). Carbonaceous shale and limestone.	Alternating marine deposition on the continental platform with subaerial volcanism in the eastern Alaska Range and submarine volcanism in the Upper Chulitna district.
Early Triassic. . . .	Volcaniclastic rocks and limestone with interlayered tuff, basalt, and locally quartz pebble conglomerate.	. . . .	
Permian		Black argillite and massive crinoidal limestone. Marine volcanic and volcaniclastic rocks (may include rocks as old as Pennsylvanian).	Volcanic island arc, built directly on oceanic crust.
Late Paleozoic . . .	Ophiolitic assemblage: serpentinite, gabbro, basalt, and bedded chert.	Dunite locally; dunites and peridotites associated with pillow greenstone, and blueschists in the Kluane Range in Canada.	Oceanic crust.

(Source: Clark, Clark, and Hawley, 1972.)

Permian-Triassic rocks in the Chulitna-Yentna belt include a red-bed sequence of hematitic sandstone, siltstone, conglomerate, breccia (Hawley and Clark, 1973, p. A3; Clark and others, 1972, p. C97). Clasts in the coarser gravel units are chiefly quartz, red chert, argillite, and mafic and intermediate volcanic rocks. Locally the matrix is tuffaceous. The tuffs and anomalous concentrations of chromium and nickel suggest volcanism near the time of sedimentation of the red beds.

Mesozoic rocks on the slopes of the Alaska Range and the Talkeetna Mountains marginal to the Susitna Lowland contain a variety of metamorphosed and nonmetamorphosed sediments. The Paleozoic rocks in the entire region are nearly barren of fossils, and age determinations are uncertain. Over much of the northwestern Susitna Lowland and adjacent slopes of the Alaska Range, a thick sequence of slate, argillite, and graywacke with conglomerate and quartzite is exposed. It is highly folded and faulted and contains large plutons. It has yielded fossils of Jurassic and Cretaceous age. Triassic(?) rocks in the Chulitna district were divided by Ross into two lithologic facies---a basal limestone, possibly 2,000 feet thick, and a very thick sequence of argillaceous rocks above it. The argillites contain lenses of tuffaceous and pyroclastic material and lenses of conglomerate. Southeast of the Chulitna-Yentna district, on the east flank of the southern Alaska Range, Jurassic and Cretaceous sediments and volcanics are widespread. A Lower Jurassic complex south of the Skwentna River and at Beluga Mountain in the Susitna Lowland contains lava, tuffs, and metamorphosed sediments (Capps, 1935, plate 1). Along the upper Skwentna River in the highlands, a complex of Upper Cretaceous and older rocks consist mainly of black argillite, slate, and graywacke with some

sandstone, conglomerate, and minor lava and tuff. The tuffs and agglomerates are of several varieties and range from black and gray through pink, green, purple, and brown. They are interbedded with porphyritic lava flows of rhyolite, dacite, and basalts.

The Mesozoic rocks in the southern Alaska Range are complexly folded and intermixed with lavas and granitic intrusive rocks. Detailed mapping and separation of the units have not been done. Smith and others (1929, p. 84) believed the group to be at least 4,000 feet thick and possibly much thicker.

North of Talkeetna townsite, metasediments of Triassic or Cretaceous age are present along the northwest margin of the batholith in the Talkeetna Mountains (fig. 43). Rocks are largely metagraywacke and slate with crystalline limestone and quartzite.

Undifferentiated Mesozoic sediments are present on both sides of the Upper Susitna and the Chulitna Rivers north of Talkeetna townsite (Capps, 1940, p. 70-72, and plate 2). Several thousand feet of possible Jurassic-age rocks form a group consisting of closely folded dark-blue and black slates with interbedded graywacke and conglomerate and locally impure limestone which strike N 50°-70° E.

Small amounts of probable Lower Jurassic sandstone, shale, and conglomerate are interbedded with andesite greenstone and quartz porphyry in a belt extending northeast from the canyons of the Sunshine and Montana Creeks. This belt is up to 8 miles wide on the west slope of the Talkeetna Mountains.

Tertiary coal-bearing sediments of nonmarine origin are believed to underlie the glacial and alluvial deposits of most of the broad Susitna Lowland. The sequence is thought to be a northward extension of the Kenai Formation in the Cook Inlet. The Tertiary sediments throughout most of the region consist of interbedded claystone, siltstone, sandstone, and some conglomerates and many coal beds. The beds are of fresh water or estaurine origin and contain abundant organic matter and plant fossils.

Capps (1913, p. 28-29) speculated on the events during the close of the Mesozoic and beginning of the Tertiary periods:

> *Between the slates and graywackes and the next younger sediments of the region, the Tertiary beds, there is a break in the geologic succession, representing a long period of time during which the slates were indurated. folded, and faulted and then intruded by great bodies of igneous rocks. After the cooling of the intrusions the rocks were subjected to erosion and an unknown amount of material was removed. It is even possible that great thicknesses of rocks of various kinds were laid down over this area to be completely removed by erosion before the beginning of Tertiary times. The relief of the Alaska Range at the end of this interval is believed to have been less sharp than at present, and broad drainage basins had probably been established, one of them in a position somewhat similar to that of the present Susitna River. The change from conditions of erosion to those of deposition was probably brought about by a gradual subsidence, which caused the materials eroded in the headwater regions of the streams to be deposited in Eocene times, in the lower portions of the basin as estuarine, fluviatile, or lacustrine beds.*

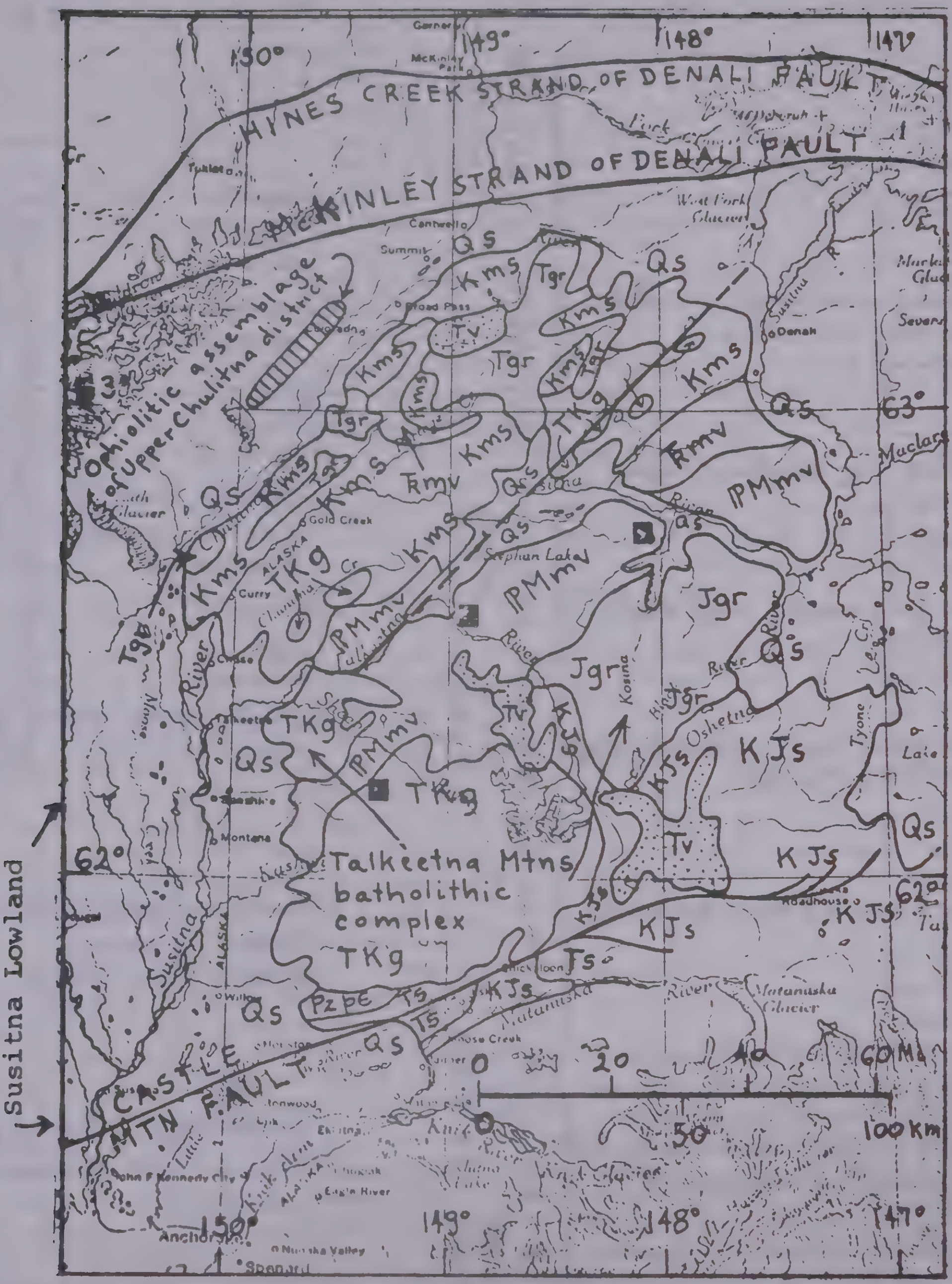


Figure 43. Generalized geologic map of the Talkeetna Mountains, Alaska. Geology modified after Capps, 1940; Clark and others, 1972; Grantz, 1960a, 1960b, 1961a, 1961b; Belkman, written communication. (Source: Csejtey, 1974.)

EXPLANATION

Sedimentary and volcanic rocks

QUATERNARY

Qs — Surficial deposits

TERTIARY

Tv — Subaerial volcanic rocks, chiefly andesitic

Ts — Clastic sedimentary rocks

CRETACEOUS(?)

Kms — Metagraywacke and slate

JURASSIC AND CRETACEOUS

KJs — Sedimentary and volcanic rocks, undifferentiated

TRIASSIC (?)

R̄mv — Metabasalt flows and tuff

MISSISSIPPIAN TO PERMIAN

PMmv — Andesitic to basaltic metavolcanic and metavolcaniclastic rocks. Includes some marble interbeds, and Triassic(?) diabase sills

PRECAMBRIAN(?) TO LATE PALEOZOIC

Pzp€ — Mica schist with altered ultramafic bodies

Plutonic rocks

TERTIARY

Tgr — Granodiorite and granite

LATE CRETACEOUS — EARLY TERTIARY

TKg — Tonalite, quartz diorite, granodiorite

JURASSIC

Jgr — Granodiorite and tonalite

Fault, approximately located; dashed where concealed

■ Location of areas mapped for present report

Figure 43. Generalized geologic map of the Talkeetna Mountains, Alaska (cont.)

In the southwest part of the region at least 2,000 feet of the finer grained coal-bearing strata are present and may be underlain by an even thicker section of poorly indurated conglomerate and pebbly sandstone that does not contain coal (Barnes, 1966, p. C1). In the northwestern part of the region a thick sequence of slightly consolidated conglomeratic beds overlies the coal-bearing sequence. Conglomeratic sequences in both areas are believed to form upper and basal members of the Kenai Formation. Plant fossils indicate a Miocene age for most of the formation, but some Pliocene and Oligocene beds may be included. A complete knowledge of the stratigraphy can be learned only by the aid of much more subsurface information than has been published. The wide distribution of outcrops along stream courses, however, indicates that the Kenai Formation underlies at least 3,400 square miles of the Susitna Lowland (Barnes, 1967, p. B24).

The most detailed descriptions of the Tertiary beds are those of the Chuitna-Beluga-Capps coal district in the southwestern corner of the Susitna Lowland and the adjacent part of Cook Inlet region north of Tyonek. This district lies across the Castle Mountain fault zone (Barnes, 1966, plate 1). Barnes mapped the Kenai Formation as three units: an upper sandstone and conglomeratic unit, a middle coal member, and a lower sandstone and conglomeratic member. The thickest continuously exposed section is south of the Castle Mountain fault in a high bluff on the east side of the Beluga River. Other exposures of the lower part of the sequence indicate the total thickness in the area is over 2,000 feet and the aggregate thickness of the Kenai Formation may be as much as 7,500 feet (Barnes, 1966, p. C19-C20). Outcrop descriptions of the Tertiary beds at various locations in the Susitna Lowland are quoted from Barnes (1966, p. C10-C15):

> *West of the upper Chuitna River, a thick sequence of light-gray to buff pebbly sandstone and conglomerate, including some tuff, is exposed on the headwaters of Straight Creek and in the south wall of the Capps Glacier trough (pl. 1, fig. 2). These beds are poorly to moderately indurated and have been extensively tilted and faulted near the mountain front. Although little or no coal and no identifiable plant fossils were found, these beds are considered to be of Tertiary age on the basis of lithologic character and the common presence of carbonized plant remains, and because similar rocks exposed on several of the east-flowing headwater tributaries of the Chuitna River are conformably overlain by typical coal-bearing Kenai beds. On the basis of this relationship, supported by the general southeasterly dip of the beds on Straight Creek, the conglomeratic series is considered to be a basal member of the Kenai Formation.*
>
> *Tertiary beds exposed along several northeastward-flowing streams between Capps Glacier and Lone Ridge (pl. 5) are intermediate in character between those on Straight Creek and on the Chuitna River. These beds include a large portion of sandstone and conglomerate but also contain finer clastic rocks and a large number of thin coal beds; this composition suggests that they represent either a transition zone between the conglomeratic lower member and the coal-bearing middle member of the Kenai Formation, or lateral equivalents of predominantly conglomeratic beds to the west. These beds were mapped as part of the lower member.*
>
> *The rocks exposed along the Beluga River consist mainly of typical coal-bearing Kenai beds. At locality 91 (pl. 5), however, gently dipping coal-bearing strata rest with distinct angular unconformity on well-indurated dark-brown pebble-cobble conglomerate that forms a narrow*

gorge and cataract in the river below this point. The conglomerate and the apparently overlying friable white pebbly sandstone have been compressed into folds that have dips of 35° to 50°. Although the more intense folding and greater degree of induration suggest a considerably greater age for the beds below the unconformity, these beds nevertheless are more similar in lithology to Tertiary rocks than to any known older rocks in the Cook Inlet basin; therefore, the unconformity here is believed to lie within the Kenai Formation as considered in this report. However, since the degree of induration suggests that the dark conglomerate is older than any other Tertiary rocks in the region, the unconformity may represent the considerable interval during which the thick conglomeratic sequence in the Straight Creek area was being deposited.

An angular unconformity judged to be intraformational and possibly of only local significance was noted on Straight Creek by Capps (1935, p. 62).

Another unusual facies of the Kenai is represented by a resistant bed of altered tuff at least 30 feet thick that forms a prominent east-facing escarpment overlooking the valley of Scarp Creek, along the west boundary of T. 14 N., R. 11 W. (pl. 5). Although neither top nor bottom of the tuff bed is exposed, its relation to nearby outcrops indicates that it is an interbed of the lower member of the Kenai Formation.

Bedded rocks exposed in the canyons of the Theodore and Lewis Rivers, northeast of the Beluga River, consist mainly of moderately to well-indurated buff sandstone and dark-gray conglomerate. The conglomerate is exceptionally resistant to erosion and closely resembles that exposed in the gorge of the Beluga River. Occasional streaks and lenses of coal and claystone indicate that these rocks are part of the Kenai Formation. The southward-dipping beds on the Lewis River appear to be basal beds deposited directly on granite. Because of this relation and their lithology, the beds on the Theodore and Lewis Rivers are included in the lower member of the Kenai Formation.

Dark-brown well-indurated conglomerate containing coal fragments is exposed in the east bank of the Susitna River at Susitna Station. Although no coal was seen in 1962, local residents stated that it was present but concealed by high water, and Capps (1929, p. 86-87) noted that lignitic coal had been mined on a small scale at this point and also on the south bank of the Yentna, 7 miles above Susitna Station. Capps' map (1929, pl. 1) shows coal-bearing rocks extending for several miles along both sides of the Yentna, upstream from a point about 6 miles above its mouth. In 1962 the only bedrock seen along this stretch of river consisted of occasional outcrops of granite or other pre-Tertiary rocks in river bluffs carved mainly in in glacial deposits. However, abundant coal float on the river bars supports the probability that rocks of the Kenai Formation are locally present but concealed by high water and by slumping of the overlying Quaternary deposits.

North of the latitude of Beluga Lake, exposures of Kenai Formation are few and mostly of small extent. Sandstone and finer clastic rocks, including a few coal beds, are exposed at several places on Coal and Drill Creeks, and at a few places on Wolverine Creek, at the base of the northwest slope of Mount Susitna. In the Talachulitna River basin, Kenai beds, including some coal, were mapped for a few miles along the main stream and also on Friday and Saturday Creeks, west of Beluga Mountain.

On Canyon Creek (pl. 2), a southern tributary of the Skwentna River, Kenai beds, including some thick coals, probably underlie the entire basin south of the main forks beneath a cover of Quaternary deposits. To the northwest on the Skwentna River, a thick section of steeply tilted beds, including several thick coals, is exposed in the south bank near the mouth of the Hayes River, and a small exposure including one or two thin coal beds also was mapped a little farther upstream on the north bank.

In the northern part of the Beluga-Yentna region, outcrops of the Kenai Formation, though mostly of small extent, are so widely distributed as to leave little doubt that the formation underlies much of the lowland area beneath a mantle of Quaternary deposits. However, significant coal occurrences were found at only a few places, notably at localities 14 and 15 (fig. 4) on Johnson Creek, a west tributary of the Yentna (pl. 2), and at localities 2, 3, 4, 8, 9, and 10 (fig. 4) in the Fairview Mountain area (pl. 2). Most of the exposed Tertiary rocks in this part of the region consist of poorly indurated conglomerate that rests conformably on finer clastic rocks and associated coal beds (fig. 3) that are limited chiefly to the northwest slope of Fairview Mountain. Although no fossils were found in the conglomeratic beds, they have undergone the same tilting and folding as the underlying coal-bearing rocks and are considered to be an upper conglomeratic member of the Kenai Formation. Weathered outcrops of the poorly indurated conglomerate are easily confused with Quaternary gravel, but the conglomerate can generally be distinguished by the greater degree of induration and by the common presence of thoroughly decayed pebbles. The upper conglomeratic member is best exposed on the upper slopes of Fairview Mountain and on the hills northwest of Pass Creek, where it consists of easily eroded rusty pebble-cobble conglomerate. Similar rocks are exposed on Bluff Creek, just south of Ruth Glacier at the north end of the map area (pl. 1); on the upper southeast slopes of the Dutch Hills; at the head of Treasure Creek; and at several points along the Nakochna and Kichatna Rivers and Johnson Creek, all western tributaries of the Yentna River.

Farther east in the northern part of the region, a few scattered outcrops along the Kahiltna River and Lake, Cache, and Peters Creeks, and along the road from Talkeetna to the Cache Creek district show this broad lowland area to be underlain mainly by sandstone and minor siltstone and claystone, and a few thin beds of coal.

The stratigraphic relations of the Kenai rocks in different parts of the Beluga-Yentna region are not completely known. The conglomerate unit exposed in the southwest part of the region clearly underlies the coal-bearing rocks of the Beluga and

Chuitna River areas, and the conglomerate unit of the Fairview Mountain area definitely overlies coal-bearing beds. Elsewhere in the region very little evidence is available from which to determine the relative age of the many isolated exposures of Tertiary rocks. Inasmuch as the principal coal-bearing sections occur in an intermittent belt near the western margin of the Tertiary basin, it seems likely that they were all laid down during the same general period of deposition and that the coal-bearing rocks of the northern part of the region are correlative with at least part of the much thicker coal-bearing section in the southern part. This conclusion is supported by the rather scanty paleontological evidence now available from a few collections of plant fossils (Wolfe and others, 1965, p. 49).

Stratigraphic sections in the southwest corner of the lowlands are shown in figure 44.

An earlier description of the Tertiary rocks in the Skwentna-Chulitna area by Capps (1935, p. 64) stated that 900 feet of unconsolidated sediments presumed to be Eocene in age rest with angular contact on highly deformed slate and graywacke of Mesozoic age and is overlain by 500 to 1,100 feet of coarse gravels of Oligocene or younger age. In the Straight Creek area there may be 2,000 feet of early Tertiary coal-bearing rocks with some interbedded volcanic deposits.

Several small isolated patches of Tertiary sediments are present along tributaries of the Upper Chulitna River. These were probably formed in local swamps and depressions and are not a part of the widespread Kenai Formation in the lowlands. One of the largest deposits is that north of the West Fork of the Chulitna River on Costello Creek, 8 miles northwest of Colorado station on the railroad and at an elevation of 2,800 feet. The Tertiary sediments are about 8 square miles in areal extent and at least 500 feet thick. Subbituminous coal has been mined from the area at the Dunkle coal mine. Ross (1933, p. 302) discussed the area:

At the northeast end of the area there are extensive deposits of more or less thoroughly consolidated gravel, sand, and clay, with local coal beds, which are of Tertiary age. In fresh exposures, either natural or artificial, this material is well-cemented rock, but the cement, which is largely calcareous, readily disintegrates on weathering. In most places these beds are somewhat deformed, dips of 10^{o} and more being common.

Conglomerate is the most abundant material in most places. Where fresh it is a hard rock, but in cliff faces it is soft enough to yield to the pick, and weathering has reduced most of it surficially to loose gravel. Interstream areas are mantled with such gravel, but the hard material exposed in most gulches proves its origin. Here, as in other areas of similar rolling topography in the region, there are scattered large erratics and thin, entirely unconsolidated beds of gravel and sand, which are doubtless Pleistocene glacial outwash. Such material is difficult to distinguish from the weathered Tertiary conglomerate, but the amount present everywhere within the area mapped appears to be small. The Tertiary conglomerate was evidently derived from

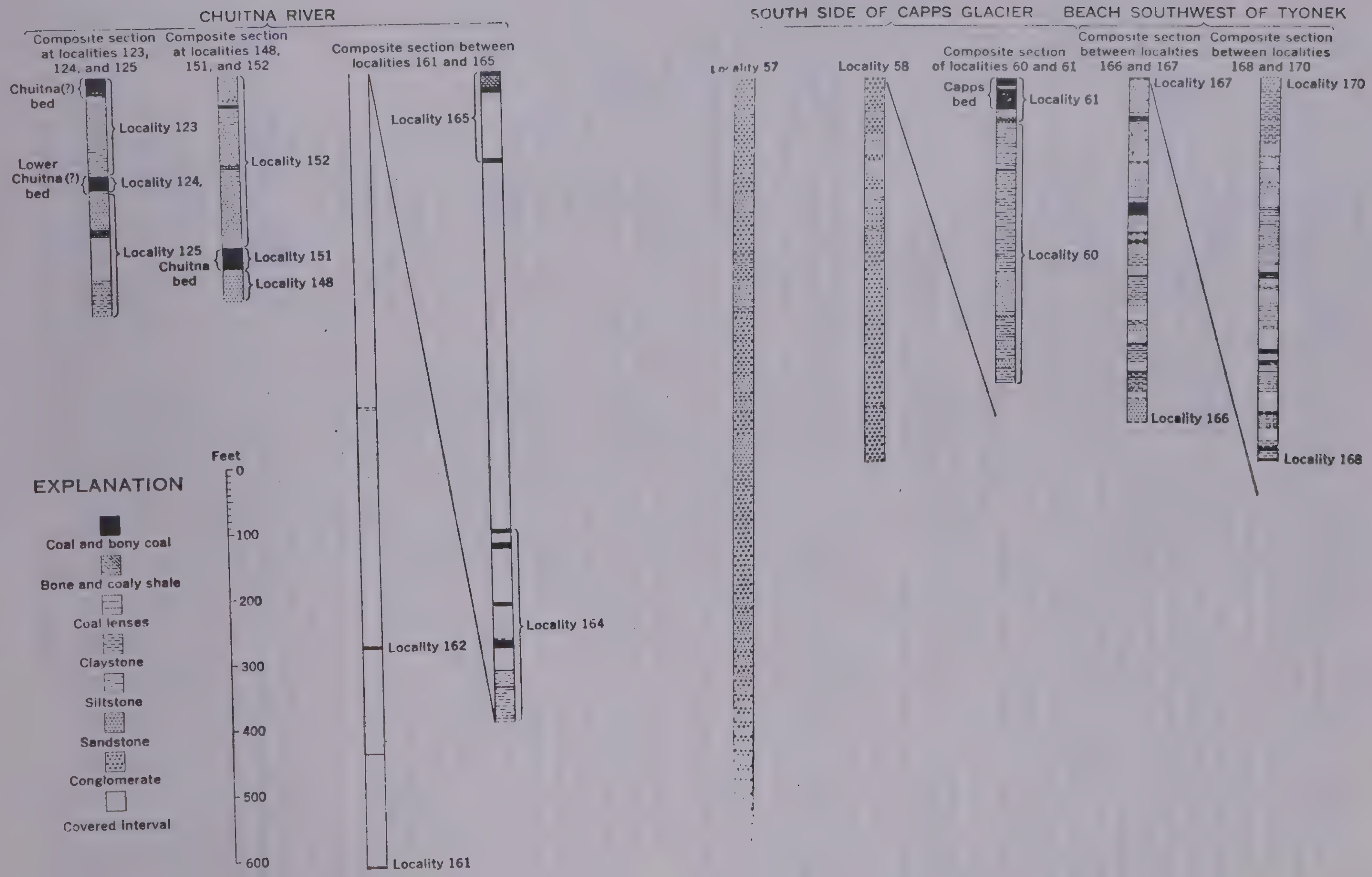


Figure 44. Stratigraphic sections of the Kenai Formation in the Chuitna River and Capps Glacier areas and along the beach southwest of Tyonek. (Source: Barnes, 1966.)

erosion from the nearby mountains, as it is composed largely of argillite pebbles and cobbles. Granitic cobbles are also plentiful, doubtless derived from such granitic intrusions as those which crop out near Costello Creek both northwest and southeast of the area mapped.[11] *Some of the characteristic reddish tuff of unit A, which is not known to crop out in the tributary area, and other representatives of the Permian(?) rocks are locally present but are not abundant.*

Much of the sandstone and grit associated with the conglomerate is composed largely of argillite. On Camp Creek and its tributary, Coal Creek, the most abundant beds are light-colored calcareous sandstone. Similar light-colored sandstone is locally interstratified with the conglomerate on Costello Creek and in gulches in the intervening area. These beds appear to have been derived mainly from the erosion of granitic rocks but have abundant calcite cement. In the vicinity of Camp Creek light-colored clayey and shaly beds, locally darkened by carbonaceous material, are more abundant than farther south, and conglomerate less so.

The thickest coal bed is 9 feet. Rutledge (1948) published several drill-hole logs from the Dunkle coal mine. Sections were logged up to 171 feet. More detailed sections of the Dunkle mine area have been compiled by Wahrhaftig (1944).

Recent mapping by T.E. Smith (1973, p. 19) disclosed an area of Tertiary non-marine sediments north of the Susitna River in the Central Talkeetna Mountains:

A previously unreported occurrence of Tertiary sedimentary rocks was mapped by T.E. Smith while conducting geological mapping in the Talkeetna Mountains D-3 quadrangle. These nonmarine sediments occupy a topographic depression over an area of 3 to 4 square miles, about 30 miles southwest of Susitna Lodge, near the Denali Highway. The rocks are exposed in at least six separate localities along the course of Watana Creek, 3 to 7 miles northeast of its confluence with the Susitna River. The outcrop sections were examined, measured, and sampled by W.M. Lyle.

The total section exposed is more than 480 feet thick, and is composed mainly of conglomerate, sandstone, and claystone, with subordinate amounts of burned clay and a few coal beds. The exposures have dips that range from nearly flat to about 35 degrees. The thickest continuous measured section had southerly dips to 15 to 17 degrees. Although the variable dips and dip direction may indicate faulting, no faults were apparent in the measured sequences. A few feet of less indurated rocks, probably Pleistocene in age, unconformably overlie these rocks in two exposures. The Tertiary beds range in thickness from a few inches to about 30 feet. The conglomerates and sandstones are lenticular and discontinuous, and are gray to gray-green whereas the claystones and siltstones are more continuous and even-bedded, and light gray to dark gray. The coal beds are thin, with seams ranging from 3 inches to 4 feet. The coals are brown and black, woody, and have little potential commercial value. The rocks appear to be dominantly stream-channel de-

posits with minor flood-plain and swamp deposits. A small collection of fossil leaves and wood was gathered from one locality and will be submitted to the USGS for identification. The exposures resemble the early Tertiary Chickaloon Formation of the Matanuska Valley.

The Union Texas No. 1 Pure Kahiltna River State exploratory well, drilled to 7,215 feet near the center of Susitna Lowland in 1964, provides some subsurface information on the Tertiary strata. The drilling report did not mention any shows of oil or gas, and the well was abandoned as a dry hole. A gamma-ray log run from 2,500 to 7,225 feet showed no abnormal radioactivity. A comment on the drilling report stated the operator still considered they were in Tertiary at 5,300 feet. An inspection of the drilling report and the mud log by the writer indicated the following lithologies.

Depths (ft)	*Lithology*
100-500	*Gravel or conglomerate with minor sandstones and shale.*
500-2,575	*Sandstone and shale. Sandstone is mostly white, loosely consolidated, fine grained, subangular to subrounded. Shales are brown, gray and black, carbonaceous; in part silty and sandy. Sand seems to be more abundant than shale throughout this interval.*
2,575-2,880	*First reported coal. Predominantly sandstone and shale.*
2,880-3,400	*Abundant coal throughout this interval with shale and sandstone.*
3,400-4,930	*Coal, shale and sandstone.*
4,930-7,264 (TD)	*Basalt and tuffs, with interbedded shale, sandstone, and a little lignite. Recovered 14' basalt from cored interval 6675-6690'. Recovered 21' of banded rhyolite with pyritic streaks from cored interval 7243-7264'.*

Igneous Rocks

A variety of plutonic bodies form a major part of the Talkeetna Mountains on the east side of the Susitna Lowland and much of the central and southern Alaska Range on the north and west (see Part 2 of this report). Smaller isolated plutons crop out west of the Yentna River and north of the Upper Susitna River. The geology of much of the upland regions is poorly known, but the composition of the intrusive rocks have been found to range from ultramafic to very alkalic. The proportion of felsic rocks and mineralization, especially in the southern Alaska Range, is sufficient to encourage exploration for uranium occurrences. Detailed descriptions of the igneous rocks in some local areas in the Talkeetna Mountains have been made by Csejtey (1974).

Reports on age determinations of the plutonic rocks in the Southern Alaska Range-Aleutian Range has been published by Reed and Lanphere (1969) and Grantz and others (1963). On the basis of potassium-argon mineral ages, Reed and Lanphere assigned the plutonic rocks of the southern Alaska Range-Aleutian Range to three age groups: (1) Early and Middle Jurassic, (2) Late Cretaceous and early Tertiary, and (3) middle Tertiary. A significant finding is that the intrusives became progressively more felsic, richer in K-feldspar, and more mineralized with decreasing age. Geologic maps of the Alaska-Aleutian Range batholith (Reed and Lanphere, 1972, 1973) show that in general the complex north of the Castle Mountain fault is composed mostly of quartz diorite, granodiorite, quartz monzonite, granite, and a group of undivided plutonic rocks, all of Cretaceous and Tertiary age.

The Alaska-Aleutian Range batholith trends northeast and generally parallels the mountain range. The main intrusive mass is about 300 miles long and 10 to 70 miles wide and narrows at the southeastern end, where it is partly covered by Tertiary volcanic rocks (Reed and Lanphere, 1973). Small inclusions of country rocks are scattered throughout the batholith, and it is cut by three recently active volcanoes. The complex just west of the southwestern corner of the Susitna Lowland is at its widest. North of the main mass of the batholith and continuing into Mt. McKinley Park, numerous isolated plutons range in size from very small bodies up to stocks several miles in diameter.

A 1:250,000 scale geologic map published by Reed and Elliott (1970) shows the variety and widespread distribution of igneous rocks in the upper Skwentna River region and westward. The same report includes much analytical data giving the metal and trace element contents of the unaltered plutonic rocks, but not uranium, thorium, or potassium. The analyses indicate that the base-metal content of the plutonic rocks were close to the average for similar types of rocks, which suggested that the anomalous metal contents found in stream sediments were derived from local areas of mineralization within the batholith. It seems that some groups of anomalous metals that were found, especially silver, copper, lead, molybdenum, tin and zinc, may be favorable for the association of uranium. The geologic map compiled by Reed and Elliott (1970, plate 10) shows a leucocratic biotite granite with accessory fluorite forming a part of the Tired Pup batholith in the northwestern part of the map area. Location of Tired Pup batholith is also shown by Reed and Lanphere (1973, fig. 2). A small granite body (Windy Fork body) north of the Tired Pup granite contains anomously high contents of Be, Sn, and Nb (Reed and Lanphere, 1973, p. 2603).

A general statement concerning the igneous rocks of the northern Aleutian Range is taken from Capps (1935, p. 71-72).

> *In the northern part of the region the continuity of the granitic areas is broken by large, irregular patches of the sediments into which the granitic materials were intruded, and along the margins of the main intrusive mass there are many smaller areas entirely separated from it, forming satellites, but probably for the most part of the same age as the main mass.*
>
> *Throughout this region the prevailing rocks of granitic texture consist of hornblende granite, hornblende granite porphyry, biotite, granite, sodic granite, granodiorite, quartz diorite, and diorite, all inclined to a porphyritic habit, with phenocrysts of feldspar.*

Those nearest the granite end of the series are most abundant, and diorites are present in minor amounts. These rocks are of medium to coarse grain, are completely crystalline, and range in color from pink and white through light to dark gray. All these rocks are readily recognized in the field as granitic rocks or as porphyry of the same general composition as the granite rocks, and in the main they are believed to belong to the same general period of igneous activity.

The granites are cut by many dikes, chiefly of granitic porphyries. Most of these dikes are only a few feet wide, but a few from 25 to 75 feet wide were seen. In addition to the acidic rocks already described there are also present in this region minor amounts of basic intrusive materials, including augitite or pyroxenite, diabase, basalt, and basalt porphyry, that occur as dikes or sills of moderate size. They are really unimportant compared with the granitic materials.

Near the head of Kenibuna Lake the writer found granular intrusive rocks that have undergone varying amounts of metamorphism. They range from fairly coarse quartz diorite, with incipient foliation, through banded gneiss to finely foliated and fissile biotite schist. Whether these gneissic rocks are merely a locally metamorphosed phase of the prevailing granitic rocks, or whether they represent a much older period of intrusion, followed by metamorphism before the intrusion of the great bulk of the granitic rocks, is not certainly known, but the evidence seems to favor the former of these alternatives.

Another description of the intrusive rocks of this region is also from Capps (1929, p. 89):

The igneous rocks of this portion of the Alaska Range are mainly of granitic character, medium to coarse grained, and completely crystalline and range in color from pink through light to dark gray. When studied under the microscope in thin section they are found to include hornblende granite, hornblende granite porphyry, biotite granite, sodic granite, and andesite porphyry. All these rocks are readily recognized in the field as granitic rocks or as porphyry of the same general composition as the granitic rocks, and they are all believed to belong to the same general period of igneous activity. In addition to the acidic rocks just described there are also present in this region minor amounts of basic intrusive materials, including augitite or pyroxenite, diabase, basalt, and basalt porphyry, that occur as dikes and sills of moderate size. They are really unimportant as compared with the granitic materials.

North of the Skwentna River area discussed above, the igneous rocks of the Yentna district were described as follows (Capps, 1913, p. 36):

The rocks of the main intrusion are of granitic textures and range in composition from granites with orthoclase feldspar predominanting through granodiorites and quartz diorites to diorites

in which the feldspar are largely plagioclase. The rocks are composed for the most part of quartz, alkali and lime-soda feldspar, biotite, muscovite, hornblende, and accessory minerals. Rocks of all textures from fine-grained rocks to coarse granites were seen, and a small amount of pegmatite was observed in the granite.

North of the areas described by Capps and near the West Fork of the Chulitna River, Ross (1933, p. 304, 305, and plate 25) found small stocks of biotite-quartz diorite porphyry, quartz diorite, and hornblende diorite porphyry. The stock near the Golden Zone mine was thought to have a maximum diameter somewhat over 4,000 feet and to be highly altered hydrothermally. The district is highly mineralized.

In the Chulitna-Yentna mineral belt along the west side of the Chulitna River, Hawley and Clark (1973, p. A4 and plate 1) mapped a part of the batholith between Ruth and Eldridge Glacier. The batholith here includes granite, quartz monzonite, quartz porphyry, and aplite. It is believed to be Tertiary in age. North of Eldridge Glacier there is a strip of ultramafic rocks largely converted to serpentinite; gabbro and basalt are abundant. A cluster of stocks composed of quartz diorite and diorite porphyry appear at the northern end of the belt near Broad Pass. Gold and a variety of other metals are associated with the igneous rocks in the area. Between the Susitna River and the upper Chulitna River is another intrusive belt of stocks similar to those described above (Tuck, 1934).

An investigation of a massive copper and zinc sulfide deposit near Shellabarger Pass in the southern Alaska Range at the head of the West Fork of the Yentna River produced information on the intrusive rocks in that area (Reed and Eberlein, 1972). The igneous rocks are within a eugeosynclinal assemblage and include volcanic graywacke, basaltic aqueous tuffs, submarine basalt, and flow breccia which are believed to rest uncomformably upon sedimentary rocks of Paleozoic age.

The eastern boundary of the Susitna Lowland is the Talkeetna Mountains. This group of mountains is roughly circular and is bounded by the Alaska Range on the north, the Copper River Basin on the east, the Matanuska Valley and Castle Mountain fault on the south, and the Susitna Lowland on the west. The Talkeetna Mountains batholith, which forms the core of the mountains, occupies about 2,500 square miles and contains glaciated peaks 6,000-9,000 feet high in the central portion. The batholithic intrusion accompanied the orogeny that initiated the Talkeetna geanticline in Late to Early Middle Jurassic time. The thermal effects of the plutons extend up to 6,500 feet into the country rocks (Csejtey, 1974, p. 39). The batholitic rocks are chiefly tonalite, quartz diorite, granodiorite and granite, but they include subordinate diorite gabbro. Late-stage aplite-alaskite rocks and quartz veins are common throughout. The general distribution of the igneous rocks are indicated by Csejtey (1974, fig. 2) and Capps (1940, plate 2), but the exact limits of the individual plutons within the batholitic complex are unmapped.

Reconnaissance investigations indicate the Talkeetna batholitic complex ranges in age from Jurassic to Late Cretaceous-early Tertiary. The age of the western two-thirds of the complex is Late Cretaceous-early Tertiary (Grantz and Lamphere, *in* Reed and Lamphere, 1969); and the Kosina batholith forming the eastern part is assigned a Jurassic age (Grantz and others, 1963). The younger age and more felsic nature of the western part of the batholith are believed to indicate that that area is more favorable for mineral deposits than the eastern part.

Recent mapping by the Alaska Division of Geological Surveys (1973, p. 14, 15) has revealed a northeast-trending belt of felsic rocks in the south-central part of the Talkeetna Mountains between the headwaters of Kashwitna River and the west fork of the Kings River. This belt is 10 miles long and 2 to 5 miles wide. The rocks within the belt range in composition from quartz monzonite to granite and locally may be classified as alaskite. These rocks may be favorable for uranium association.

Tertiary effusive and clastic rocks, which include basalt, volcanic breccias, agglomerates, and tuffs, are widely scattered throughout the Talkeetna region and cap many of the mountains. These materials were deposited at different times during the Tertiary period.

Csejtey (1974) reported several Mesozoic units of tuffaceous material up to 1,650 feet thick. It is possible that uranium could have been leached from these units and transferred to the Susitna Lowland.

Structure

The Susitna Lowland lies between two major fault systems, the Denali fault to the north in the Alaska Range and the Castle Mountain fault to the south, near Cook Inlet. Thus, it occupies a relative shallow Tertiary basin that is separated from the Cook Inlet Basin by the Castle Mountain fault and by a near-surface belt of Paleozoic or older metamorphic rocks.

The axis of the Jurassic-Cretaceous Talkeetna geanticline trends northeast across the Susitna Lowland between the Alaska Range and the Matanuska geosynclines and extends through the Talkeetna Mountains and southern Alaska Range (Payne, 1955; Grantz and others, 1963). Growth of the Alaska Range and the Kenai-Chugach Mountains during Eocene time with the development of the Tertiary trough at the sites of the present Cook Inlet and Susitna Lowland led to the accumulation of nonmarine sediments. Post-Eocene uplift caused mild deformation of the Eocene sediments, which became tilted and folded near the margins of the basins; however, in the lowlands away from the mountains, the dips are gentle to flat, rarely exceeding 15° (though there are some exceptions in the southwestern part of the Susitna Lowland and near the Castle Mountain fault).

Folds and high-angle faults are common in the pre-Tertiary rocks exposed on the flanks of the Alaska Range. These seem to trend northeastward and to have a significant relation to the location of mineral deposits (Hawley and Clark, 1973, p. A5). The upper Chulitna fault has been mapped by Hawley and others (1969).

Economic Geology

The mineral resource of the Susitna Lowland currently receiving the most attention is coal. The Tertiary Kenai Formation contains beds of coal over a wide area, as indicated by small scattered exposures along streams. Barnes (1967, p. B24) estimated that coal-bearing rocks underlie at least 3,400 square miles of the lowland beneath a mantle of glacial and alluvial deposits. The deposits that are potentially the most valuable lie in a 400-square-mile area in the southwest part of the region in the basins of the Beluga and Chuitna Rivers, where a number of beds of subbituminous coal range to thicknesses of more than 50 feet. Although the deposits are still undeveloped, there is presently much interest by industry in the Beluga-Chuitna coal.

The region is considered to have a moderate potential for oil and gas, but only one exploration well has tested the sediments in the basin. The test was the Union Texas Petroleum No. 1 Pure Kahiltna River State in section 33, T 23 N, R 8 W, drilled to 7,265 feet in 1964 and abandoned.

A variety of metallic minerals occur in lode deposits in mining districts in the mountains and foothills bordering the Susitna Lowland. No large-scale mining is being conducted today, but there has been considerable lode gold produced in the past, and the future potential for gold, copper, lead, and zinc is good.

The best known mining district within the region is the Willow Creek gold district, located in the southwestern part of the Talkeetna Mountains, near Palmer. This district was discussed in the section on the Matanuska Valley.

A 100-mile-long northeast-trending mineral belt on the northwest side of the lowland in the foothills of the southern Alaska Range has been roughly divided into three districts: the Chulitna district on the north, the Curry district in the middle, and the Yentna district on the south (fig. 45). A group of precious and base-metal lodes on the West Fork of the Chulitna River between Talkeetna and Broad Pass was explored between 1911 and 1942. Small tonnages of copper and gold were shipped (Capps, 1919; Berg and Cobb, 1967, p. 23-26; and Ross, 1933). Besides gold, the principal metallic minerals are arsenopyrite, pyrite, pyrrhotite, chalcopyrite, sphalerite, and argentiferous galena. Minor stibnite is present in some of the veins and anomalous molybdenum tin, cadmium, and bismuth have been found by spectrographic analyses of samples (Hawley and Clark, 1968; Hawley and others, 1969). A list of ore minerals that have been noted in the combined Chulitna-Yentna belt is given in table 5. The lodes are genetically related to quartz diorite porphyry and occur as replacement masses in calcareous rocks, disseminated deposits in breccia pipes, and in tabular lenses in fault and shear zones which can be traced for as much as 3,000 feet. Oxidation has penetrated only a few feet from the surface.

The most noteworthy occurrence in the Upper Chulitna district is that at the Golden Zone mine, which produced gold and silver from disseminated deposit in a breccia pipe. Other mines and numerous prospects contain metallic minerals in replacement lodes. Antimony, bismuth, and silver are ubiquitous components of the arsenic-rich veins. Chromium and nickel occur in a 25-mile-long belt of serpentinite bodies near the northern end of the belt northeast of Eldridge Glacier (Hawley and others, 1969; Hawley and Clark, 1973).

Adjacent to the southern end of the Upper Chulitna district and generally between the Ruth and Eldridge Glaciers is the Curry district, which is occupied mostly by an extension of the batholitic rocks of the Alaska Range. These rocks consist mostly of granite, quartz on monzonite, quartz porphyry, and aplite. Hawley and Clark (1973, p. A8) found anomalous amounts of copper and molybdenum in limonitic rocks in knots within the intrusives, but the district is less mineralized than those on either side.

The Yentna district at the southern end of the mineralized belt is drained principally by the Yentna and Kahiltna Rivers. It contained numerous placer gold deposits which have produced more than $7 million. Tin, platinum, and chromite have been recovered in the placer workings. Gold-bearing lodes associated with felsic dikes which cut the Mesozoic sediments are numerous. Most of the placer mining was on the Cache, Peters, and Long Creeks and along the Kahiltna River.

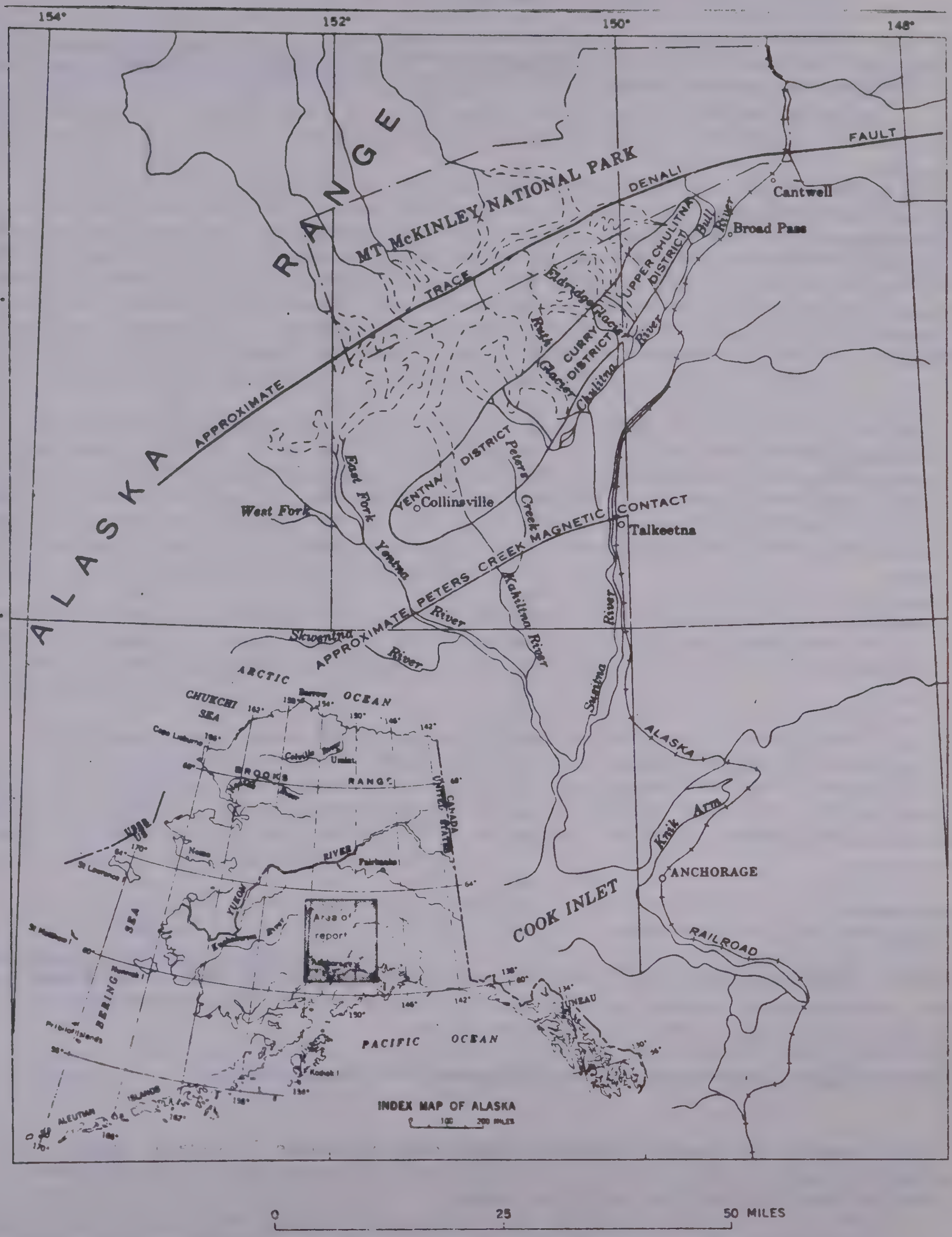


Figure 45. Index map showing location of the Chuitna-Yentna mineral belt. (Source: Hawley and Clark, U.S. Geol. Survey Prof. Paper 758-A.)

TABLE 5.-Ore minerals of the Chuitna-Yentna mineral belt.*

	Abundance	Distribution	Placer	Lode
Native elements:				
Gold - - - - - - - - - - - - - -	M	W	X	X
Copper - - - - - - - - - - - - -	Sp	Y	X	- -
Platinum[1]- - - - - - - - - - -	Sp	Y	X	- -
Sulfides and sulfosalts:				
Arsenopyrite - - - - - - - - -	A	W	X	X
Pyrite - - - - - - - - - - - - -	A	W	X	X
Pyrrhotite - - - - - - - - - -	M	Ch	- - -	X
Chalcopyrite - - - - - - - - -	M	Ch	- - -	X
Sphalerite - - - - - - - - - -	M	Ch	- - -	X
Galena - - - - - - - - - - - - -	M	Ch	- - -	X
Do - - - - - - - - - - - - - -	Sp	Y	X	- -
Stibnite - - - - - - - - - - -	Sp	Ch	- - -	X
Do - - - - - - - - - - - - - -	O	Y	X	- -
Molybdenite- - - - - - - - - -	O	Ch	- - -	X
Bismuthinite - - - - - - - - -	O	Ch	X	- -
Argentite- - - - - - - - - - -	O	Ch	- - -	X
Chalcocite - - - - - - - - - -	O	Ch	- - -	X
Tennantite(?)- - - - - - - - -	O	Ch	- - -	X
Oxides:				
Magnetite- - - - - - - - - - -	M	Y	X	- -
Ilmenite - - - - - - - - - - -	M	Y	X	- -
Do - - - - - - - - - - - - - -	Sp	Ch	- - -	X
Chromite - - - - - - - - - - -	M	Y	X	- -
Do - - - - - - - - - - - - - -	O	Ch	- - -	X
Cassiterite- - - - - - - - - -	M	Y	X	- -
Do - - - - - - - - - - - - - -	Sp	Ch	- - -	X
Wodginite (Ta, Nb, Sn, Fe, Mn) O_2 - - - - - - - - - - -	O	Ch	- - -	X
Rutile(?)- - - - - - - - - - -	Sp	Y	X	- -
Uranothorianite- - - - - - - -	Sp	Y	X	- -
Tungstates:				
Scheelite- - - - - - - - - - -	Sp	Y	X	X
Phosphates:				
Monazite - - - - - - - - - - -	M	Y	X	- -

[1]Mertie (1919) described two varieties of platinum metals in the Yentna placers; one a dark-gray or bronze type in flaky grains of <1 mm size; the other a bright silver type in more crystalline grains.

(Source: Hawley and Clark, U.S. Geol. Survey Prof. Paper 758-A.)

*A major mineral of several deposits: M-Moderate abundance in several deposits; Sp-sparse, may be locally abundant; O-only one occurrence known; W-widespread; Y-Yentna only; Ch-Chulitna only; X-present.

Next in importance is the Fairview Mountain area, where platinum was a significant by-product to placer mining. Molybdenum-bearing quartz lenses in a felsic stock 3-4 miles long by 1 mile wide east of Hayes Glacier have been prospected. Uranothorianite in sparse amounts has been reported from placers in the Yentna district (Hawley and Clark, 1973, table 1). The Yentna district has been more fully described by Capps (1913), Mertie (1919) and Capps (1925, p. 53-61).

A massive sulfide deposit was recently discovered high in the southern Alaska Range in the headwaters of the West Fork of the Yentna River near Shellabarger Pass. The occurrence has been mapped and described by Reed and Eberlein (1972). Copper and zinc-bearing sulfide deposits occur mainly as replacements in sedimentary and metamorphic mafic volcanic rocks of Triassic or Jurassic age. The deposits contain, in order of decreasing abundance, pyrite, marcasite, sphalerite, chalcopyrite, galena, and pyrrhotite. The deposits appear to have commercial possibilities. The tenor of the ore averages between 1 and 1.5 percent copper, 0.8 and 1.7 percent zinc, 0.9 and 2.4 ounces of silver per ton, and a small amount of lead.

The western Talkeetna Mountains adjacent to the eastern side of the Susitna Lowland have not been mapped geologically other than in a reconnaissance fashion, and they are still underprospected. Numerous conspicuous gossan zones and geochemical anomalies suggest that metallic deposits remain to be discovered. Two areas which have been prospected are the Iron Creek area on the southeast side of Wells Mountain and the Little Falls Creek area on the Talkeetna River, near the center of the Talkeetna Mountains quadrangle.

The claims on Iron Creek were prospected about 1910 for gold, copper, and iron. A mineralized shear zone up to 20 feet wide cuts altered andesite and contains pyrite, arsenopyrite, chalcopyrite, hematite, and bornite (Capps, 1919, p. 197-205).

The mineral occurrences on the upper Talkeetna River were investigated by Rose (1967) and Anderson (1969). Rose believed that the series of rocks in that area correlates with the limestone, slate, shale, and quartzite, and andesite of the Iron Creek area. Showings of copper, gold, and silver were found in the outcrops. Stream-sediment analyses revealed anomalous amounts of copper and zinc, and one sample had a high nickel content.

Molybdenum has been found in small amounts 2 miles south of Curry, close to the Alaska Railroad (Smith, 1942, p. 189). Flakes of molybdenum in fractures are associated with small quartz veins and narrow aplite dikes. Molybdenum was also reported to be present on Portage Creek near Chulitna, but details were not available (Smith, 1942, p. 190).

A small "bog iron" deposit consisting of limonite and probably other hydrous iron minerals is located in Goose Creek drainage, 1.3 miles southeast of Montana on the Alaska Railroad (Berg and Cobb, 1967, p. 35).

Radioactivity Investigations

The most extensive investigation for radioactivity in the Susitna Lowland region was in the Cache-Peters Creek area of the Yentna district during 1945 (Robinson, Wedow, and Lyons, 1946, 1945; Hardner and Reed, 1945, p. 5, 15-17, appendix). Radioactivity was measured with a Geiger-Müller counter at 445 field

stations and in 526 screened samples. The maximum eU of the screened samples was 0.009 percent. The maximum value obtained from the concentrates from sluice boxes was 0.065 percent eU. The highest value was from Peters Creek. Higher eU values were reported from the Yentna district prior to the 1945 investigation. The earlier assays are shown in table 6; in light of the later determinations it can probably be assumed that the earlier materials were more concentrated. Up to 300 feet of Tertiary and Quaternary gravels are exposed along the valley of Cache Creek, and gold has been produced from gravels of every age and origin in the district.

In the headwaters of the Skwentna River near Shirley Lake (T 22 N, R 17 W), anomalous radioactivity was found in a volcanic tuff-breccia unit. The entire report on the occurrence (Freeman, 1963, p. 29-30) is given here:

> *Shirley Lake, about 100 miles northwest of Anchorage, lies between Happy River and Portage Creek about a mile north of the Skwentna River (fig. 1). The region was visited by S.R. Capps in 1926 (Capps, 1935), and the prospect was previously visited by J.J. Matzko in 1954 (written communication).*
>
> *Anomalous radioactivity was found in 1954 in a unit of tuff and tuff-breccia that underlies a ridge along the north side of Shirley Lake. The tuff and tuff-breccia are indurated but, except for a little epidote, do not appear to be metamorphosed. The unit is broken by many joints and by a few faults.*
>
> *The radioactive areas are very small, at the most a few feet in length, and occur in and adjacent to joint surfaces. It seems likely that the radioactive rock was formed by the deposition of small amounts of uranium that migrated with subsurface water moving along joints in the tuff unit. The uranium may have been leached from the tuff and then deposited when the water partly evaporated upon reaching the surface.*
>
> *Exploration work at the prospect consists of a few shallow pits in the tuff unit. The pits have not disclosed any extension of radioactive rock below the surface or away from the joints and therefore show the dependence of the radioactive rock on the joints.*
>
> *The maximum amount of uranium detected in samples from Shirley Lake by the U.S. Geological Survey is 0.021 percent (J.J. Matzko, written communication). A prospector reported that a sample from the area assayed 0.29 percent uranium, which is possible considering the spotty nature of the radioactivity. The joint-controlled occurrences of the radioactive rock and its low grade are unfavorable indications for the presence of ore-grade material at Shirley Lake.*

Slightly radioactive coal was reportedly collected by geologists studying the coal deposits in the Costello Creek area in the Chulitna district west of Broad Pass (Matzko and Freeman, 1963, p. 43), but no anomalies were found during a second investigation. The writer visited the Dunkel coal mine (Eakins, 1969, p. 16) and did not find any radioactive anomalies in the coal-bearing beds. An outcrop of coarse-grained igneous rock near the mine site did produce two and one-half times the background count on a geiger counter. The writer also examined the Silver King silver-antimony prospect, about 3 miles south of the Dunkle coal mine, where mineralization is associated with a quartz diorite stock that has intruded metasediments and greenstone. No anomalous radioactivity was detected.

TABLE 6.-Data on concentrates collected in Yentna district before 1945.

Sample no.	eU (percent)	U (percent)	ThO_2 (percent)	Location
482	0.025	----	----	Canyon Creek, tributary to Long Creek, tributary to Tokichitna River.
521	.001	----	----	Do.
519	.019	----	----	Poorman Creek, tributary to Cottonwood Creek, tributary to Peters Creek.
520	.229	0.090	0.06	Do.
522	.035	----	----	Willow Creek, tributary to Cottonwood Creek.
260	<.001	----	----	Bird Creek, tributary to Peters Creek.
474	.064	----	----	Peters Creek, below Cottonwood Creek.
518	.029	----	----	Do.
473	.024	----	----	Cache Creek, above Gold Creek.
476	.002	----	----	Nugget Creek, tributary to Cache Creek.
523	.030	----	----	Do.
475	<.001	----	----	Cache Creek.
250	<.001	----	----	Thunder Creek, tributary to Cache Creek.
478	.005	----	----	Do.
524	<.001	----	----	Do.
479	<.001	----	----	Dollar Creek, tributary to Cache Creek.
525	.119	.07	.035	Cache Creek, above Windy Creek.
526	.003	----	----	Windy Creek.
517	.237	.14	.05	Sholan Bar, Kahiltna River, 2 to 3 miles below Cache Creek.
480	.036	----	----	Round Bend Bar, Kahiltna River.
481	.023	----	----	Do.
527	.190	.08	----	Do.
254	.005	----	----	Mill Creek, tributary of Lake Creek.

A heavy-mineral fraction from a placer in the Mount Spurr area yielded monazite and zircon with an eU content in the 0.0X range (Bates and Wedow, 1953, table 2).

The hematitic copper deposit on Iron Creek in the Talkeetna Mountains was investigated by Tolbert and Nelson (1952, p. 7-9). The eU values obtained with a portable survey meter were 0.002 percent or less.

During 1918, a sample of carnotite was submitted to the Fairbanks Assay Office by an Alaska Railroad construction worker named Grotto. The exact location from which the material was taken was not determined, and there is some doubt that it was from the region at all. If Grotto's find was authentic, the ore was probably found somewhere along the railroad belt, possibly in the Kobe-Susitna River portion which was under construction in the summer of 1918 (Moxham and West, 1953; Wedow 1956, p. 85-86).

A very cursory radiometric survey was conducted by Moxham and West (1953) along the Alaska Railroad belt, which crosses the Susitna Lowland. No significant anomalies were noted.

During the summer of 1973, Bertram V. Starke, representing Uranerzbergbau, visited the writer and stated that his firm had conducted some aerial radiometric surveys and some water and rock sampling in the Susitna Lowland that year, but was not able to reveal the results.

Discussion

Nonmarine Tertiary sediments underlie at least 3,400 square miles of the Susitna Lowland and, combined with the occurrence of felsic plutons in the Alaska Range and Talkeetna Mountains, could be a favorable environment for sedimentary uranium deposits. The abundance of alkalic intrusive rocks, mineralization, and tuffaceous beds in the Chulitna-Yentna mineral belt suggest that the northern and northwestern part of the lowlands may offer the best target for sedimentary types of deposits. Traces of uranothorianite in the Yentna placer gold district and small amounts of uranium in the tuffs near Shirley Lake are additional encouragements.

The Permian-Triassic hematitic and tuffaceous sandstone and conglomerate in the Chulitna-Yentna belt may deserve study to determine if sedimentary uranium could be associated with the sequence.

The belt of felsic rocks---especially the alaskite---mapped by the Alaska Division of Geological Surveys in the south-central part of the Talkeetna Mountains are favorable for vein-type and disseminated uranium deposits. Thick tuffaceous units in the Talkeetna Mountains are a possible source of uranium in sedimentary rocks in the lowlands.

Most of the Susitna region is easily accessible, and considerable aerial surveying, ground work, and drilling seem justified to test both the highlands and lowlands for uranium potential.

THE ALASKA PENINSULA

The Alaska Peninsula of southwest Alaska extends about 475 miles southwest from Iliamna Lake and Kamishak Bay to Unimak Island, where the Aleutian Island

chain begins (fig. 46). The principal feature of the region is the Aleutian Range, which extends the length of the peninsula as a narrow, rugged chain of ridges 1,000 feet in altitude, interspersed with volcanoes 4,500-8,500 feet in altitude. Most volcanoes have glaciers or ice fields on the upper slopes. The margin of the peninsula on the northwest side consists of the Nushagak-Bristol Bay Lowlands, which are surfaced by marsh and tundra. The Katmai National Monument, site of the famous Mount Katmai eruption in 1912 and the Valley of Ten Thousand Smokes, occupies 4,200 square miles of the northeastern end of the peninsula; however, the area is closed to mineral exploration, and will not be discussed in detail.

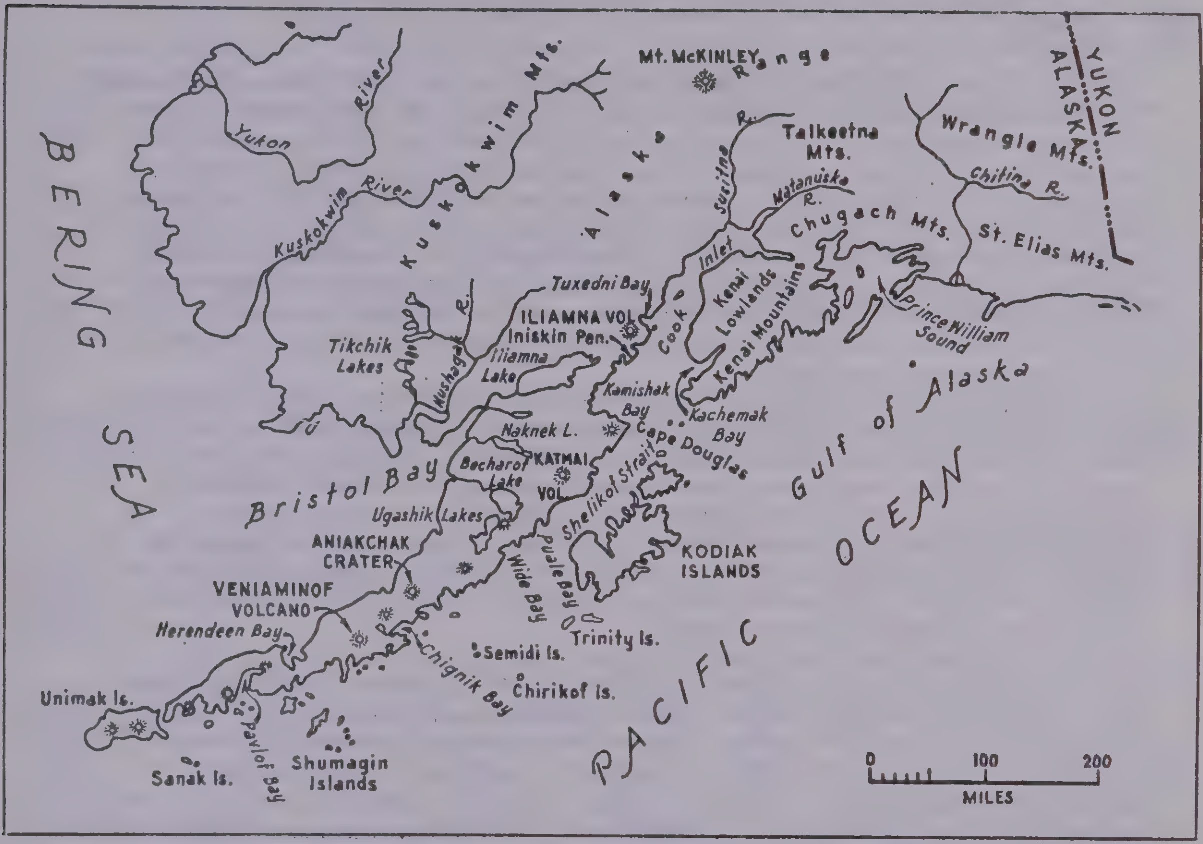


Figure 46. Index map of Alaska showing principal geographic localities. (Source: Burk, 1965.)

The Alaska Peninsula is sparsely populated and is occupied mainly by military installations, weather stations, airports, and isolated fish-processing settlements; there are no roads. The average temperatures of the peninsula are not as low as most other sections of the state e.g., that of Cold Bay is 37.9° F. Despite this relative moderation, however, work is often severely hampered by adverse weather, particularly the aircraft operations. The peninsula is notorous for high winds, much rain and fog, and generally overcast skies. Chignik has recorded 151 inches of annual precipitation. From Katmai National Monument south, there are no trees---probably because of the strong winds. Vegetation consists of tundra and alder thickets. Bedrock exposures are generally good throughout the region.

Because the Alaska Peninsula is a potential petroleum province, most detailed geological studies have been made by petroleum companies; these have not been released to the public. Several exploratory wells have been drilled. The most complete available geologic report of the region is that by Burk (1965), from whom much of the information in this section is taken. Another useful publication is the bibliography on the Alaska Peninsula and adjacent area by Kelly and Denman (1972). The region is covered by the following 1:250,000 scale USGS topographic maps: Mount Katmai, Naknek, Karluk, Ugashik, Bristol Bay, Sutwik Island, Chignik, Stepovak Bay, Port Moller, Fort Randall, and Eagle Pass.

The following geologic history of the Alaska Peninsula is quoted from Burk (1966, p. 645):

> *The Alaska Peninsula area is of particular geologic interest because it is part both of the Aleutian volcanic arc and the continental margin of southwestern Alaska. Topographically, the peninsula is a ridge, rising above the general level of a broad marine platform consisting of the Bering Sea shelf and the Shumagin-Kodiak shelf. However, the structural and stratigraphic history of these shelves appears to be separate from that of the Alaska Peninsula. The islands of the Shumagin shelf consist largely of a thick flysch sequence of late Mesozoic turbidites and volcanic rocks containing ultramafic bodies and are intruded by earliest Tertiary quartz diorite plutons. Similar rocks comprise the Kenai and Chugach Mountains.*
>
> *The oldest dated rocks of the Alaska Peninsula are Permo-Triassic carbonate and volcanic rocks and Lower Jurassic debris, both of which were intruded by an Early Jurassic granite batholith. Uplift and erosion of these rocks caused the appearance of the Alaska Peninsula, and the accumulated arkosic debris now constitutes a thick Middle Jurassic to Lower Cretaceous sequence. Middle Cretaceous deformation was relatively small-scale but rocks of this age are absent from the Alaska Peninsula. Uppermost Cretaceous strata constitute a thin, but widespread transgressive sequence.*
>
> *Marine and nonmarine volcanic rocks and debris accumulated to great thickness throughout the early Tertiary, especially in the outer parts of the Alaska Peninsula; lesser amounts were deposited on the newly uplifted Shumagin shelf. These were deformed gently at the time of mid-Tertiary plutonic intrusions along the present Pacific shore. Miocene debris from older rocks, as well as new volcanic material, accumulated in great thickness, but Pliocene strata occur only as thin patches of volcanic rocks in the mountains and as isolated bodies of marine sediments near the present coast. Both the Pliocene volcanic and sedimentary rocks rest discordantly on older rocks. All of the prominent structural features of the Alaska Peninsula were formed by post-Miocene deformation.*
>
> *The Alaska Peninsula thus may have existed as early as Middle Jurassic time. The Shumagin-Kodiak shelf was formed during the earliest Tertiary. The Aleutian volcanic arc and trench are no older than Tertiary, and the trench may be relatively young. The greatest thickness of Tertiary sediments accumulated in isolated depressions that were only partly controlled by earlier structure, e.g., in the Gulf of Alaska, Cook Inlet, Bristol Bay, and at the outer parts of the Alaska Peninsula.*

Sedimentary Rocks

The following descriptions of the sedimentary rocks on the Alaska Peninsula are taken from Burk (1965, p. 11-122). Stratigraphic relationships are shown in the correlation chart in figure 47 and their general distributions appear on the geologic map in figure 48.

Paleozoic Rocks

The oldest rocks positively dated on the Alaska Peninsula are Permian. These locally form a 4,000-foot sequence of limestone and volcanics at Puale Bay. Older rocks may underlie Permian rocks north of the Kamishak Bay-Lake Iliamna area, but the presence of unexposed Paleozoic rocks elsewhere on the peninsula is highly speculative, due to the complicated relationships and a lack of fossils in the older rocks.

Triassic-Middle Jurassic Rocks

Triassic sediments are exposed only on the tip of Cape Kekurnoi and at Kachemak Bay, where they consist of up to 1,400 feet of dense limestone and chert with interbedded sandstone and shale. The Triassic beds grade upward into Lower Jurassic tuffaceous sandstone and volcanic conglomerate.

The Lower Jurassic rocks are represented by a single locality near the southern coast at Puale Bay of the upper Alaska Peninsula. The sequence consists of 2,300 feet of tuffaceous sandstone, calcareous sandstone and shale, limestone, and volcanic conglomerate.

A prism of Middle Jurassic to Upper Cretaceous clastic sedimentary rocks with thin beds of first-cycle volcanic ash forms a large portion of the outcrops on the Alaska Peninsula. The composite thickness is over 22,500 feet (Gates, Grantz, and Patton, 1968, p. 22).

Middle Jurassic rocks on the west shore of Cook Inlet represent one of the most complete Middle Jurassic sequences in the world. There, 10,000 to 12,000 feet of fossiliferous siltstone, sandstone, and conglomerate form the Tuxedni Group and the Chitina Formations. On the Alaska Peninsula, however, Tuxedni-age rocks are known only along the coast in the Wide Bay-Puale Bay area where 1,750 feet of sandstone, shale, and conglomerate comprise the Kialagvik Formation. The formation contains marine fossils. It is overlain by 3,600-7,500 feet of sandstone, shale, and conglomerate belonging to the Middle Jurassic Shelikof Formation.

The Shelikof Formation at Wide Bay contains 1,800 feet of siltstone, sandy siltstone, sandstone, thin ash beds, and abundant calcareous concretions in the lower part of the unit. The middle part at both Wide Bay and Puale Bay consists of 1,000 to 1,500 feet of massive gray sandstone and siltstone, with conglomerate containing boulders of granitic and dioritic rocks. An upper unit 900 to 1,500 feet thick consists of hard, dark-gray siltstones with limestone lenses. The Shelikof Formation is much thicker and contains much more coarse detritus than its equivalent, the Chitina Formation. The Shelikof Formation is richly fossiliferous. It is everywhere overlain by arkoses of the Upper Jurassic Naknek Formation.

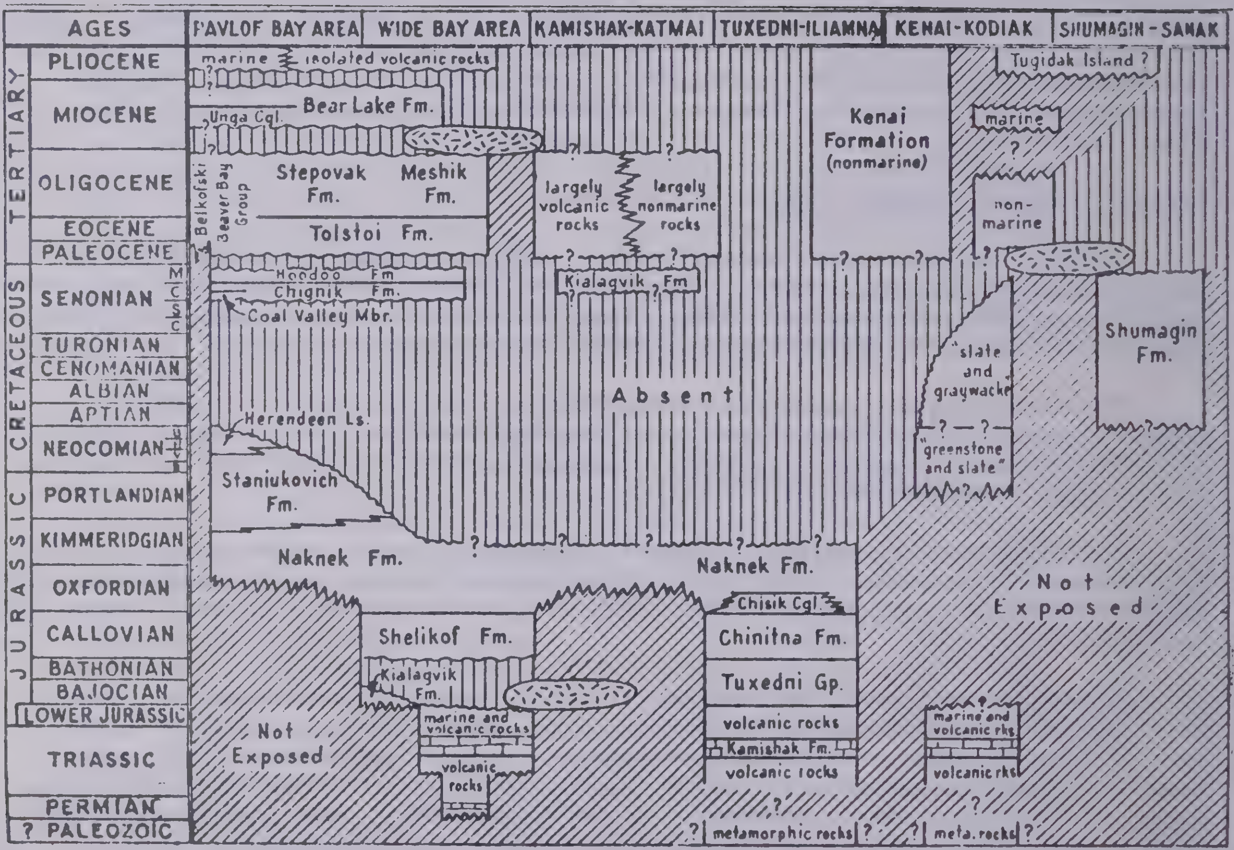


Figure 47. Correlation chart showing stratigraphic relationships in Alaska Peninsula area. (Source: Burk, 1965.)

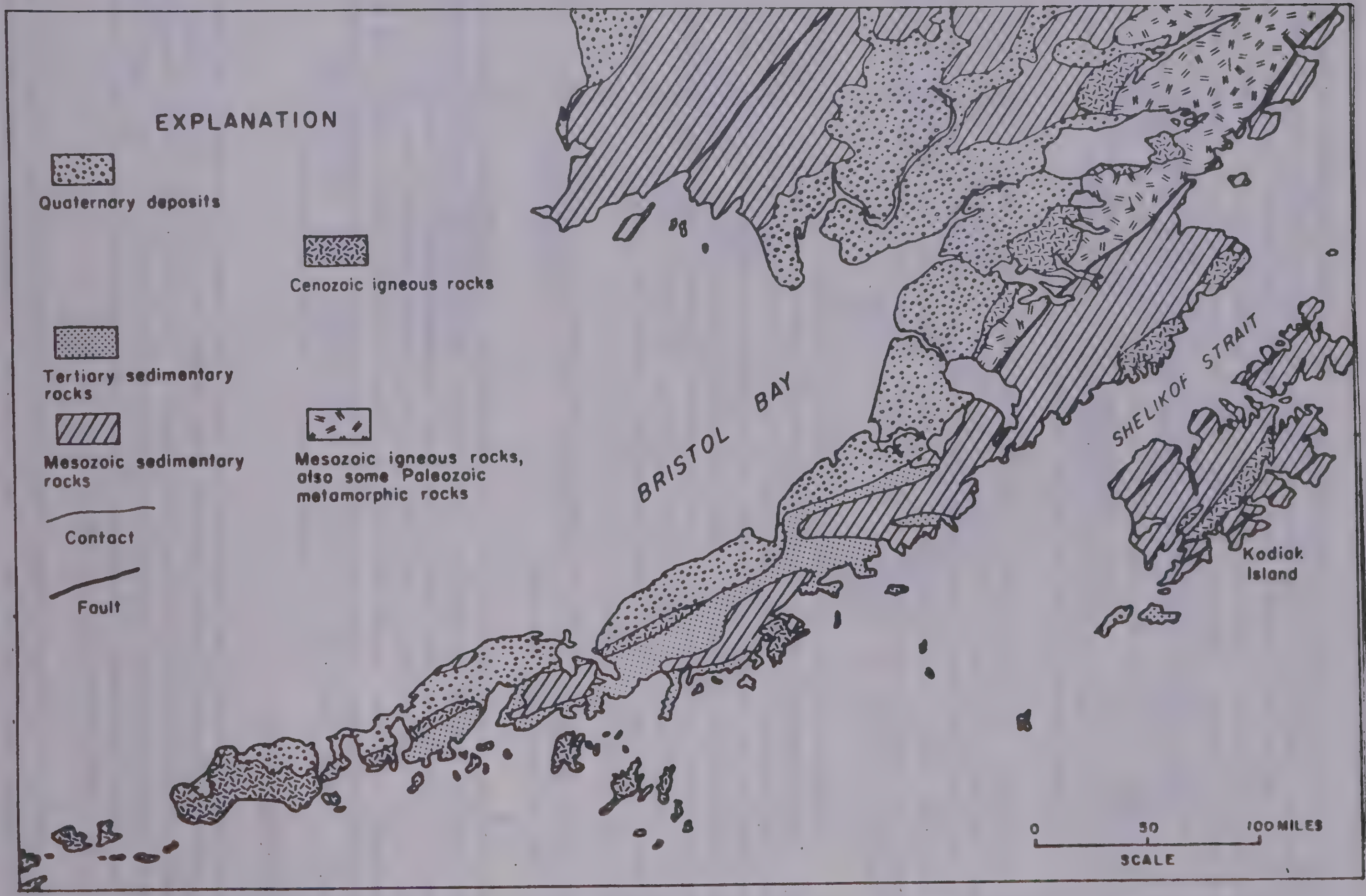


Figure 48. Generalized geologic map of the Alaska Peninsula and adjacent areas. (Source: Kelley and Denman, 1972.)

Upper Jurassic and Lower Cretaceous Rocks

Upper Jurassic and Lower Cretaceous rocks in southern Alaska are exposed in a belt 900 miles long from Pavlof Bay on the Alaska Peninsula to the Chitina Valley south of the Wrangell Mountains. The Upper Jurassic and Lower Cretaceous strata form a distinctive arkosic sequence derived from a rapidly eroding hornblende-biotite granite terrain. No major disconformities are within the sequence, but the top is marked by an erosional unconformity. These rocks are widespread on the Alaska Peninsula (Burk, 1965, fig. 8) and consist of up to 8,000 feet of arkosic sandstone, siltstone, conglomerate, and claystone of the Naknek and Staniukovich Formations. The Lower Cretaceous Herendeen Limestone, also rich in arkosic debris, overlies the Staniukovich Formation at Port Moller. Figure 49 indicates the grain compositions of these formations.

The lower part of the sequence, the Naknek Formation, has a relatively varied lithology, but consists mostly of arkosic material. Carbonaceous plant material is generally present, and marine pelycypods are locally abundant. The formation contains a few ash layers. Its thickness is about 5,000 feet but may locally reach 10,000 feet. An early description of the Naknek Formation near the Katmai area is quoted from Spurr (1898, p. 169-171):

> *The Naknek series consists of a great thickness of granitic arkose and of conglomerate which generally contain pebbles of granite. All of these sedimentary rocks are evidently derived from the destruction of a land mass which consisted largely of hornblende-biotite granite. There are probably some volcanic flows interstratified with the arkose and conglomerates, although it is not absolutely proved that those examined may not be intrusive. The series is cut by an andesite-basaltic (aleutitic) lava of later age, especially along the axis of the range, where the amount of volcanic rock is very great.*

Throughout the whole series the arkoses carry abundant fossil remains, both of plants and of marine organisms.

The Staniukovich Formation at its type section on Staniukovich Mountain, between Port Moller and Herendeen Bay, consists of about 2,000 feet of feldspathic sandstone, siltstone, arkose, and a few thin conglomerates. It characteristically weathers to a yellowish brown and contains locally great abundances of *Buchia*. The Herendeen Limestone, which locally overlies the Staniukovich Formation at the Port Moller Bay area, consists of 800 feet of gray, fossiliferous, arenaceous limestone.

Upper Cretaceous Rocks

Unconformably overlying the Upper Jurassic and Lower Cretaceous sediments is a transgressive sequence grading upward from nonmarine clastic rocks through marine sandstone and black siltstone and shale. The lower sandy part constitutes the Chignik Formation with the Coal Valley Member at its base. The upper argillaceous sequence represents the Hoodoo Formation. Correlations of the Cretaceous rocks of the Alaska Peninsula are shown in figure 47.

The coal-bearing Chignik Formation was named from exposures along the shores of Chignik Lagoon and Chignik Bay. The formation is exposed at many localities southwest of Wide Bay. At Herdeen Bay, the lower 1,250 feet of the Chignik is

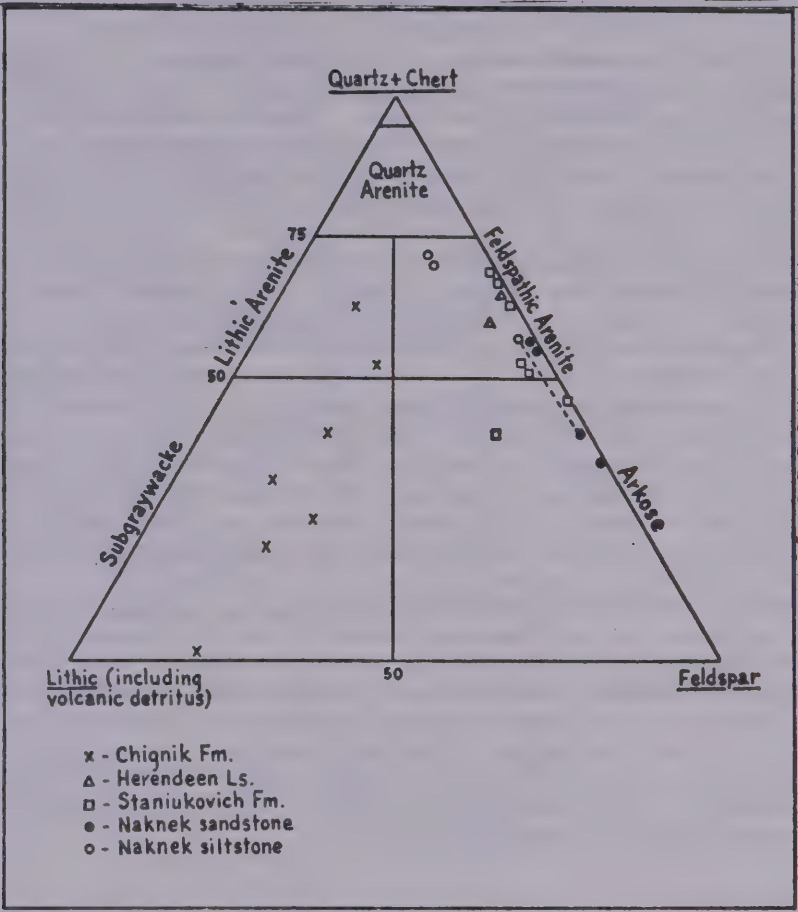


Figure 49. Grain composition of principal Mesozoic rocks of Alaska Peninsula. (Source: Burk, 1965.)

largely nonmarine. This basal unit, the Coal Valley Member, consists of carbonaceous to lignitic shales, siltstones, and sandstones which are locally bentonitic. They weather to a typical orange and reddish brown. The upper one-third of this member consists of a pebble and cobble conglomerate containing largely volcanic, granitic and chert clasts, which appear to grade laterally into marine beds similar to those of the upper part of the Chignik Formation. Interest in the coal of the lower unit led to its investigation by several geologists, particularly Atwood (1911) and Knappen (1929).

The upper Chignik sequence is about 2,000 feet thick in the Herendeen Bay area and consists of marine argillite, sandstone, and siltstone, which weather to a characteristic chocolate brown to dark tan. The Chignik sandstones are generally subgraywackes and lithic arenites. They locally are feldspathic but are distinctly different than the Upper Jurassic arkoses and feldspathic sandstones. The source terrain for the Chignik Formation is uncertain.

The sandstones of the upper Chignik Formation grade into an interval of black siltstone and shale, termed the Hoodoo Formation. The Hoodoo Formation is fairly widespread southwest of Wide Bay, but it has been removed by erosion in many places. It is often difficult to distinguish the Hoodoo Formation from the overlying Early Tertiary deposits. The most complete section of the Hoodoo Formation is at the type area between Herendeen and Pavlof Bays, where it is at least 3,000 feet thick. The Hoodoo siltstone and shales weather easily and the exposures are very poor. The beds are typically complexly folded and faulted due to the incompetence of the rocks. The most distinguishing feature of the Hoodoo Formation is the weathering of the siltstone into prismatic splinters. Fossils are rare, and carbonaceous material is present only locally or as finely disseminated particles.

Another unit believed to be Jurassic or Cretaceous in age is a thick, dark flysch sequence adjacent to the Shumagin batholith on the Shumagin Islands. The unit, the Shumagin Formation, is at least 10,000 feet thick, but the total thickness may be twice this amount. It consists of dark-gray sandstone, black shale, and siltstone. The Tertiary Shumagin batholith has been intruded into it and individual beds are highly deformed. The sandstone units range up to 50 feet thick, but generally are not over 10 feet. They contain quartz, feldspar grains, and volcanic fragments. Carbonaceous material is locally abundant. Some sandstones in the lower part are conglomeratic.

Tertiary Rocks

Rocks of all Tertiary epochs are present on the Alaska Peninsula. They consist of 25,000 to 30,000 feet of interbedded volcanic-rich clastic sediments of marine and nonmarine origin. Alternating marine and nonmarine beds indicate conditions of an oscillating strand line. Tertiary rocks crop out at intervals along the entire length of the peninsula, but outcrops are most abundant along the southeast coast from Wide Bay southward to Pavlof Bay. The entire Tertiary sequence is difficult to separate into mappable units on the basis of lithology alone. More detailed studies of the fossil assembledge will help in understanding the relationship of the units. The correlation of Cenozoic rocks are shown in figure 50, and the distribution of Tertiary rocks appear on figure 51.

Burk (1965, p. 115) stated:

> *The Paleogene rocks throughout the Alaska Peninsula consist almost entirely of andesitic and basaltic volcanic debris. This*

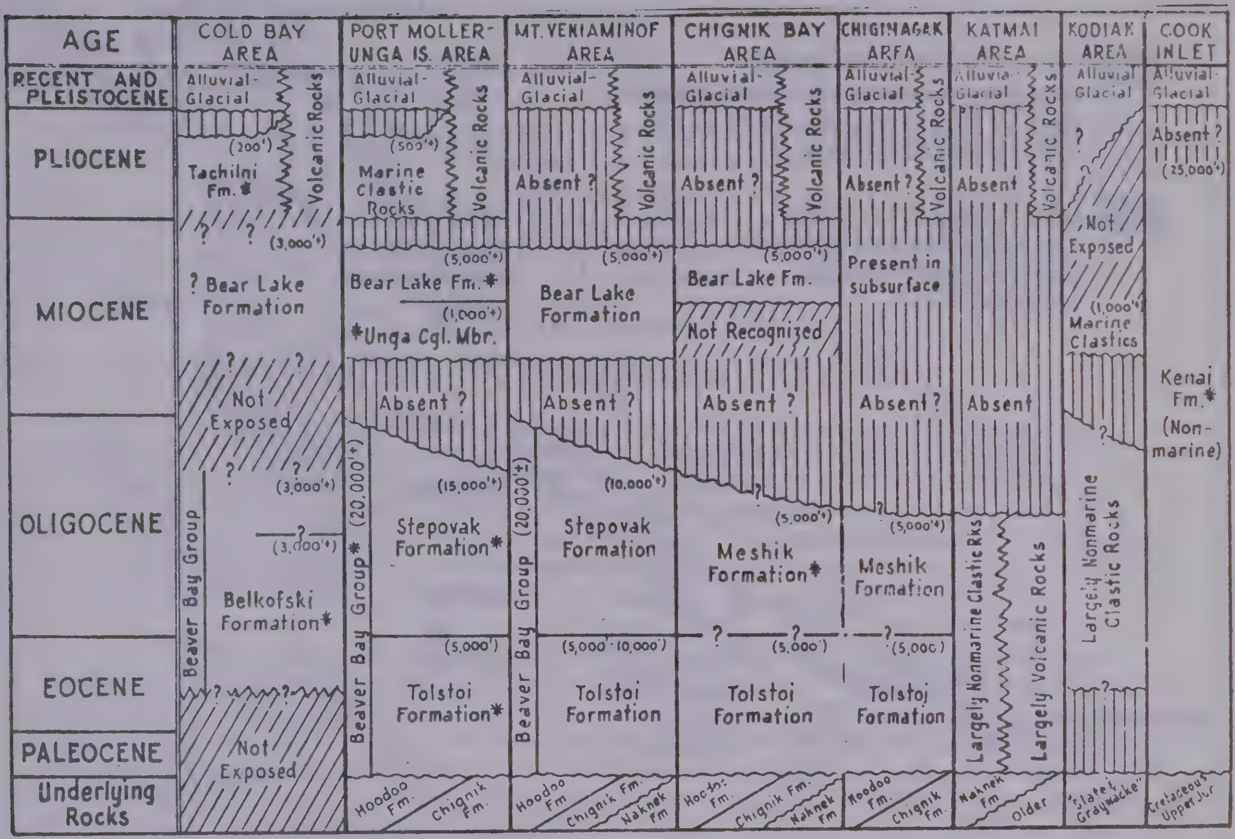


Figure 50. Correlation chart of Cenozoic rocks of Alaska Peninsula and adjacent areas. Localities shown on figure 51. Asterisk indicates type only. (Source: Burk, 1965.)

material has been weathered, abraded, and transported to varying extents and deposited as silt, sand, conglomerate, and breccia. All the rocks are poorly sorted, containing a large range in grain sizes. The sandstones are all volcanic subgraywackes.

Unconformably overlying the Cretaceous and older rocks are 5,000 feet of Paleocene and Eocene rocks, predominantly nonmarine and brackish black siltstone with interbedded volcanic sandstone and conglomerate, flows, sills, and volcanic breccia belonging to the Tolstoi Formation. The sandstone and conglomerate consist of poorly sorted volcanic debris classified as volcanic subgraywackes. The black siltstones are very sandy and carbonaceous, and some thin beds of gray claystone have large pyrite crystals. The Tolstoi Formation has been recognized as far north as the Wide Bay area and as far south as Pavlof Bay and the Shumagin Islands. Marine fossils are rare, but plants are common to abundant in the lower part of the formation at many locations. At the Mount Chiginagak area south of Wide Bay, the Tolstoi Formation is 3,000 feet thick and has brown to yellow sandstone and pebble conglomerates, carbonaceous shale, and thin beds of lignite. Bedding is regular to channeled and cross bedded.

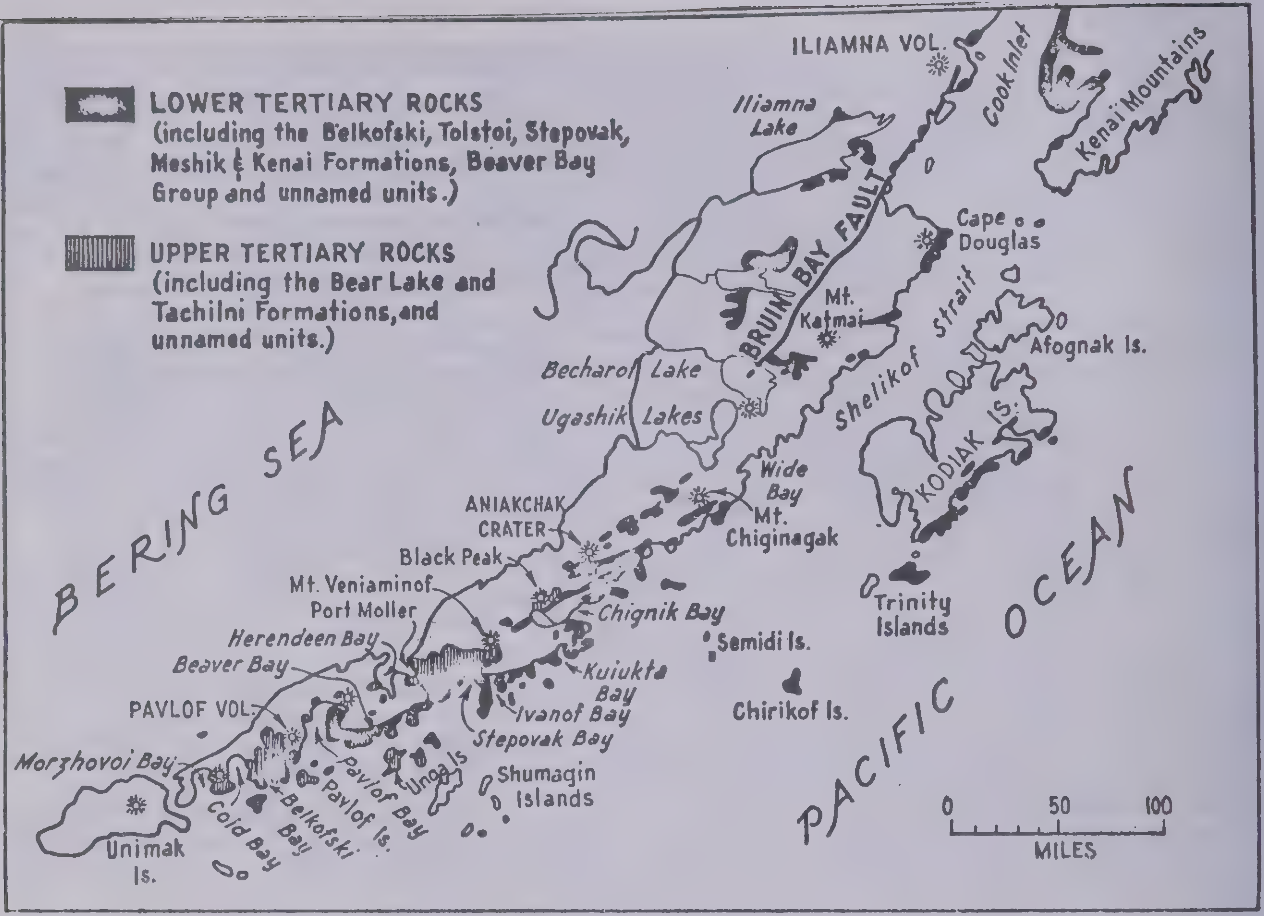


Figure 51. Index map of Tertiary rocks of Alaska Peninsula. (Source: Burk, 1965.)

Conformably overlying the Tolstoi Formation are 5,000 to 15,000 feet of interbedded Oligocene volcanic sandstone, conglomerate, and black siltstone. The sequence in the Port Moller, Unga Island and Mount Veniaminof areas is named the Stepovak Formation; in the Cold Bay area it is the Belkofski Formation; and in the Wide Bay area it is the Meshik Formation (Burk, 1965, fig. 17). Because of the similarity of the Tolstoi Formation and the overlying Stepovak Formation, they are not always differentiated, and in many areas the total sequence is named the Beaver Bay Group.

The type section for the Stepovak Formation is near Chichagof Bay. Both here and throughout most of the mainland, the Stepovak Formation consists of more than 7,000 feet of interbedded volcanic sandstone and conglomerate with black siltstone units up to 1,000 feet thick. The siltstone units contain abundant calcareous concretions. The sandstones are greenish gray to tan and brown. They contain grains of mafic rocks, argillite, and chert. The mafic minerals are scarce, but hornblende and clinopyroxene have been noted. Cross bedding is common. All rocks are locally carbonaceous, and lignitic coal is present in the upper part of the sequence. Marine invertebrates are abundant locally.

The Meshik Formation in the Chignik Bay area is equivalent to the Stepovak Formations and is of similar composition. It contains abundant carbonaceous plant remains and silicified tree stumps more than 1 foot in diameter.

Igneous Rocks

Permian-Jurassic Mafic Rocks

Mafic volcanic and intrusive rocks of late Paleozoic and possibly early Mesozoic age lie in a broad syncline in the Kaiyuh Mountains (fig. 52b). They are flanked on the east and west sides by older metamorphic rocks. The unit appears to be a typical ophiolite suite and consists of pillow basalt, diabase, gabbro, radiolarian chert, serpentinized peridotite and dunite, and slate. All are altered to greenstones. The largest of the ultramafic bodies is about 20 square miles in area.

Upper Cretaceous and Lower Tertiary Felsic and Volcanic Rocks

Felsic extrusive and hypabyssal rocks, chiefly latites and rhyolites, are widespread in the eastern part of the eastern part of the Yukon-Koyukuk province, though they are not abundant within the Galena Basin (fig. 52b). The felsic volcanic rocks range in age from Late Cretaceous to early Tertiary. Subaerial flows are as much as 2,000 feet thick. A potassium-argon age of 85 m.y. was obtained from a crystalline tuff in the Selawik region, and an age of 58 m.y. was obtained from a flow in the Koyukuk River valley.

These rocks form a deposit about 20 miles long in the north-central part of the Galena Basin at a large bend in the Koyukuk River. Smaller deposits lie to the east and northeast in the Kokrines--Hodzana Highlands and northwest in the Selawik Hills. A long, narrow belt of the felsic volcanic rocks trends along the west side of the Yukon River south of the Kaltag fault.

Upper Tertiary(?) and Quaternary Basalt

Nearly flat-lying olivine basaltic flows cover more than 2,000 square miles in the Buckland River region west of the Galena Basin and in the eastern part of the Seward Peninsula, and on the southeastern edge of Norton Sound. Most of these flows are believed to be Pleistocene and Pliocene in age, but some fresh cinder cones in the Buckland River and St. Michaels areas are Recent. These basalts do not occur in or adjacent to the Galena Basin.

Cretaceous and Tertiary Granitic Rocks

The Hogatza pluton belt extends east-west 225 miles north of the Galena Basin and includes the Selawik Hills, Purcell Mountains, and Zane Hills. These granitic rocks are mid-Cretaceous in the western part of the belt and late Cretaceous in the eastern part. They are composed of monzonites, syenite, quartz monzonite, granodiorite, and various subsilic alkaline rocks. The granitic rocks in this belt are favorable types for uranium associations and have been discussed at more length in the section of this report on the "Alkaline Intrusive Belt of West-Central Alaska and the Selawik Basin Area."

Mid-Cretaceous intrusives of quartz monzonite and granodiorite are also widespread in the northeast-trending crystalline complex of the Kokrines-Hodzana Highlands. These rocks also may be favorable for uranium, though a detailed description was not located. Eakin (1916) called the intrusive rocks in the Kokrines Hills and Ray Mountains granites, monzonites, and some diorites. These rocks are chiefly massive but locally altered to augen gneiss and mica schist.

Middle unit (Kim). Mostly sandstone: near top dominantly pale-olive to medium-gray, fine to medium-grained, thick-bedded, crossbedded, and lenticular; near base dominantly dark greenish-gray, muddy, very fine to fine-grained, and thin-to thick-bedded. Subordinate dark-gray siltstone and shale. Grades into upper unit. Thickness, 1,100 feet, measured between Koyukuk and Nulato. Marine mollusks abundant. Littoral marine origin.

Lower unit (Kil). Dominantly sandstone dark-gray and dark greenish-gray, muddy, thin- to thick-bedded, very fine to fine-grained. Subordinate dark-gray shale and siltstone. Grades into middle unit. Base not exposed. Minimum thickness of 300 feet measured between Koyukuk and Nulato. Marine mollusks abundant. Offshore marine origin.

(4) The fourth unit of the Lower and Upper Cretaceous rock described by Patton is the "Marginal trough deposit." A narrow band of quartz conglomerate extends 450 miles along the north and south margins of the Yukon-Koyukuk province, but it is not present in the Galena Basin. This unit also contains minor amounts of quartz sandstone, shale, thin bituminous coal beds, and ash-fall tuffs. The beds rest unconformably on Early and Late Cretaceous coal-bearing sequence and lap onto pre-Cretaceous igneous and metamorphic rocks, rimming the province.

Available descriptions of the marginal trough deposits suggest the possibility of a sedimentary-type host rock for uranium. The writer examined coarse conglomerate belonging to the above sequence for a few miles and along strike south of Walker Lake in the Brooks Range. No anomalous radioactivity was detected with a hand-carried scintillometer. However, the material exposed in the area examined did not contain carbonaceous material, coal, or ash beds, and it seems that other localities further west, where they are present, should be examined.

Mapping of the Kateel River and Nulato quadrangles (Patton, 1966; Bickel and Patton, 1957) distinguished four Cretaceous sedimentary units on the west side of the Galena Basin. The unit named "Nonmarine shale, siltstone, and sandstone" includes the cross-bedded sandstone and coal. This map would be helpful in investigating the nonmarine unit for uranium.

Tertiary Rocks

Tertiary beds have not been reported in the Galena Basin, and Patton (1973, p. A14) wrote that the aeromagnetometer profile across the Koyukuk Flats and mapping around the margins of the basin indicate highly magnetic rocks (volcanics) at shallow depths and that no "substantial" thickness of Cenozoic strata are thought to be present, except in a trench along the Kaltag fault. Small deposits of coal-bearing Tertiary rocks lie along the Yukon River above the junction with the Tanana River, over 150 miles to the east of Galena Basin, and small amounts of coal, possibly of Eocene age, were found along the Yukon River, 10 miles southeast of Galena (Mertie, 1936, p. 136).

Quaternary Rocks

Unconsolidated deposits of Quaternary age are more than 300 feet thick in place within the Galena Basin, although a few bedrock knobs project above the alluvium (Weber and Pewe, 1961, p. B371). Cenozoic deposits probably overlie Cretaceous rocks in the basins in the region, but Tertiary sediments could be present below the alluvium in places.

mid-Cretaceous sediments by better sorting and a high percentage of quartz and other resistant detritus. The probable source of the deposits was the metamorphic terrane in the Kaiyuh Mountains and the Kokrines-Hodazana Highlands bordering the southeastern margin of the province (Patton, 1973, p. A10). Some ash-fall tuff intercalated with the sediments at the northern part of the region was presumably derived from the volcanic centers farther north.

Exposures of the coal-bearing sequence along the Yukon River have been described by Martin (1926, p. 445-448) and Patton and Bickel (1956). Descriptions by Patton and Bickel of the Cretaceous rocks along the Yukon River between Ruby and Kaltag follow:

Border Facies

Includes most of the rocks exposed along the north bank of the Yukon River between the Melozitna River and the Yukon River; near the southeast margin of the Koyukuk Cretaceous basin.

Upper unit (Kbu). Variable lithology. Mostly yellowish-orange, yellowish-gray, and gray, ferruginous, in places calcareous, shale, siltstone, sandstone, and conglomerate. Sandstone is fine to coarse grained and thin to thick bedded. Conglomerate is usually granular, rarely pebbly; in places feldspathic. Subordinate greenish-gray graywacke conglomerate, pale-olive sandstone, and dark-green siltstone. Thickness unknown. Plant remains. Thought to be chiefly nonmarine in origin.

Lower unit (Kbl). Mostly greenish-gray conglomerate and sandstone. Conglomerate is lenticular, poorly sorted, and poorly stratified. Contains subangular to round pebbles and cobbles of mafic and acidic intrusive and extrusive igneous rocks, varicolored chert, quartz, schist and, in lesser amounts, limestone, quartzite, gneiss, slate, and shale imbedded in a muddy lenticular; bedding commonly graded. Subordinate shale and siltstone, dark-gray; locally calcareous. Near the top yellowish-orange conglomerate with subangular pebbles of chert, quartz, and schist in a hard, siliceous matrix and yellowish-orange feldspathic sandstone. Grades into upper unit. Base not exposed. Minimum thickness of 1,200 feet measured between Melozitna River and Yukon River. Marine mollusks and worm tubes. Probably of marine origin.

Interior Facies

Includes most of the rocks exposed along the north and west bank of the Yukon River between the Yukon River and Kaltag; in central part of the Koyukuk Cretaceous basin.

Upper unit (Kiu). Mostly dark-gray and olive-gray shale and siltstone. Siltstone is micaceous. Near base, fine- to coarse-grained, lenticular, crossbedded, locally friable, thick-bedded, salt-and-pepper sandstone; locally some thin lenses of quartz and chert granule and pebble conglomerate. Subordinate very fine to fine-grained, micaceous, thin- to medium-bedded, gray to yellowish-orange sandstone. Bituminous coal in beds as much as 20 inches thick. Thickness, 1,100 feet, measured between Koyukuk and Nulato. Plant remains abundant. Fresh- and brackish-water mollusks. Nonmarine origin.

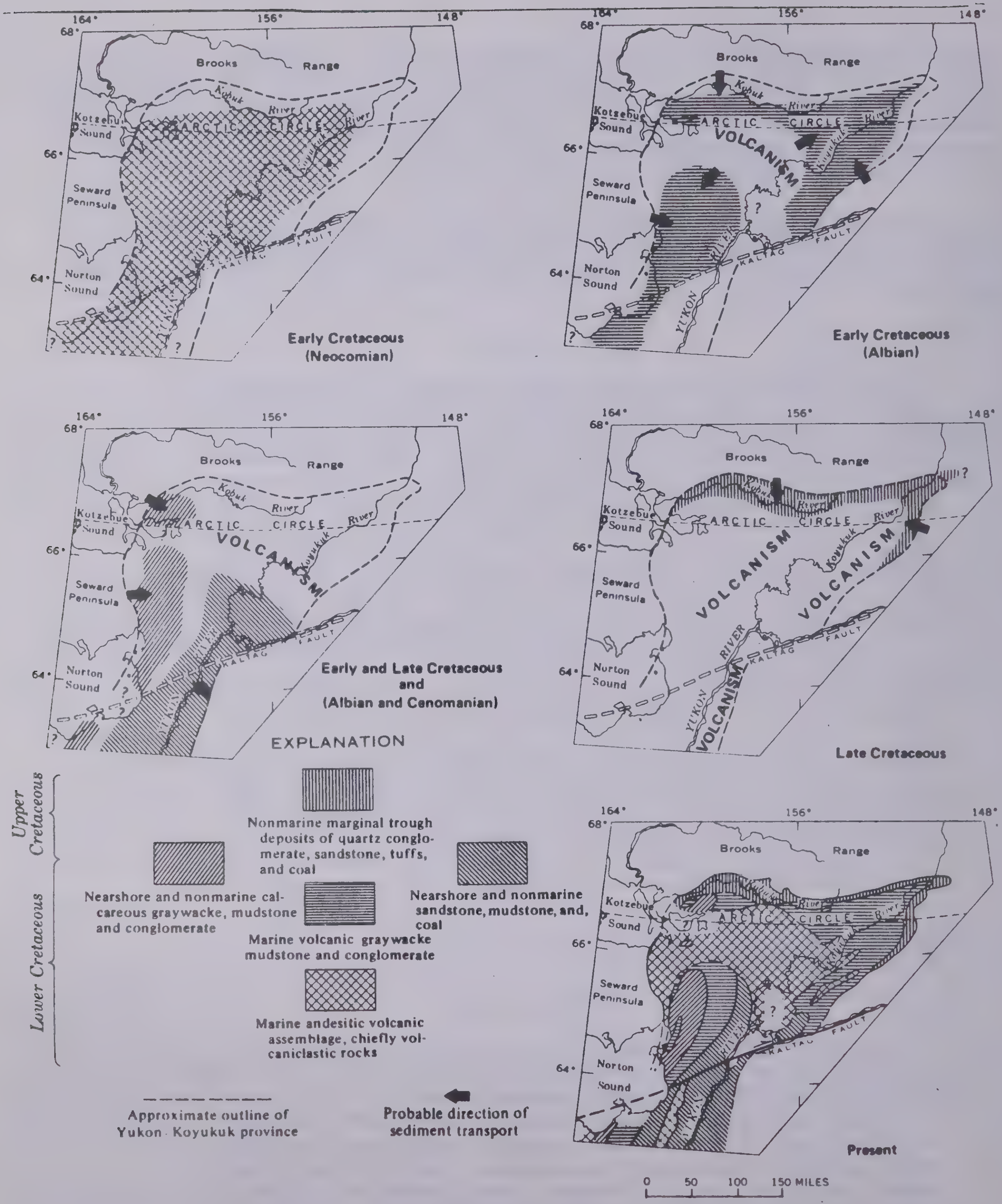


Figure 55. Cretaceous depositional basins and present-day distribution of major stratigraphic units in northern Yukon-Koyukuk province. Cretaceous depositional basins not palinspastically restored for offset along Kaltag Fault. (Source: Patton, Jr., 1973.)

Lower Cretaceous Rocks

The basal part of the Cretaceous sequence consists of marine andesitic flows, volcanic detritus, and beds of lithic tuffs that seem to underlie much of the region. This group of rocks is present across the broad northern end of the Galena Basin and surrounds the granitic plutons in the Hogatza plutonic belt (fig. 55). Magnetometer profiles suggest that Cretaceous lavas also underlie large parts of the Galena Basin. Smaller occurrences of Lower Cretaceous rocks appear east of the Galena Basin on the west flank of the Kokrines Hills. In the Koyukuk River area, andesites belonging to this sequence have been referred to as the Koyukuk Group (Patton, 1973, p. A7). The thickness of the sequence on the Koyukuk River below Hughes is estimated to be 5,000 feet, but the full thickness may be several times this amount.

Lower and Upper Cretaceous Rocks

Cretaceous (rocks largely of terrigenous origin) underlie much of the Yukon-Koyukuk province. Their nonmarine origin and the carbonaceous content of some units prompt a discussion of their uranium potential. The rocks of this sequence were deposited rapidly during the mid-Cretaceous time and are characterized by wide variations in thickness and lithology. Early writers included these rocks in the Bergman Group of the upper Kuskokwim region. The lower part is equivalent to the Ungalik conglomerate in the Norton Basin area, and the upper part is equivalent to the Kaltag and Nulato Formations in the Yukon River Valley (Patton, 1973, p. A9 and fig. 6). Cass (1959) mapped parts of the Kaiyuh Mountains as Ungalik Conglomerate and the broad area west of Galena Basin as the Cretaceous Shaktolik Group. However, Patton divided the Cretaceous into four unnamed units, from the oldest to the youngest: (1) volcanic graywacke and mudstone, (2) calcareous graywacke and mudstone, (3) sandstone, siltstone, shale, and coal, and (4) marginal trough deposits. Generalized descriptions of these four units follow.

(1) The volcanic graywacke and mudstone constitute a very thick sequence, possibly more than 20,000 feet, of marine turbidites deposited during Early Cretaceous time. These sediments underlie a broad area between the Yukon River and Norton Sound (Gates and others, 1968, p. 3-48). The average composition included about 40 percent volcanic rock fragments and plagioclase, 35 percent argillaceous matrix, and less than 10 percent quartz.

(2) Shallow-water calcareous graywacke and mudstone as much as 5,000 feet thick overlie the volcanic sequence. These sediments become coarser westward and grade into nonmarine conglomerates and coal-bearing deposits that lap onto the adjoining volcanic and metamorphic terrane.

(3) Sandstone, siltstone, shale, and coal have an aggregate thickness of at least 10,000 feet (Patton, 1966). This is a regressive sequence that grades upward from marine shale and sandstone into nonmarine shale, siltstone, sandstone, and coal. This sequence is believed to have covered the entire present-day Galena Basin (fig. 52b). Present occurrences are located in a northeast-trending belt along the western side of the basin and along the Yukon River south of the basin and the Kaltag fault. A smaller area is present northeast of the Kokrines Hills.

Winnowed strandline sandstone and quartz conglomerate locally interfinger with marine and nonmarine beds. The unit can usually be distinguished from the other

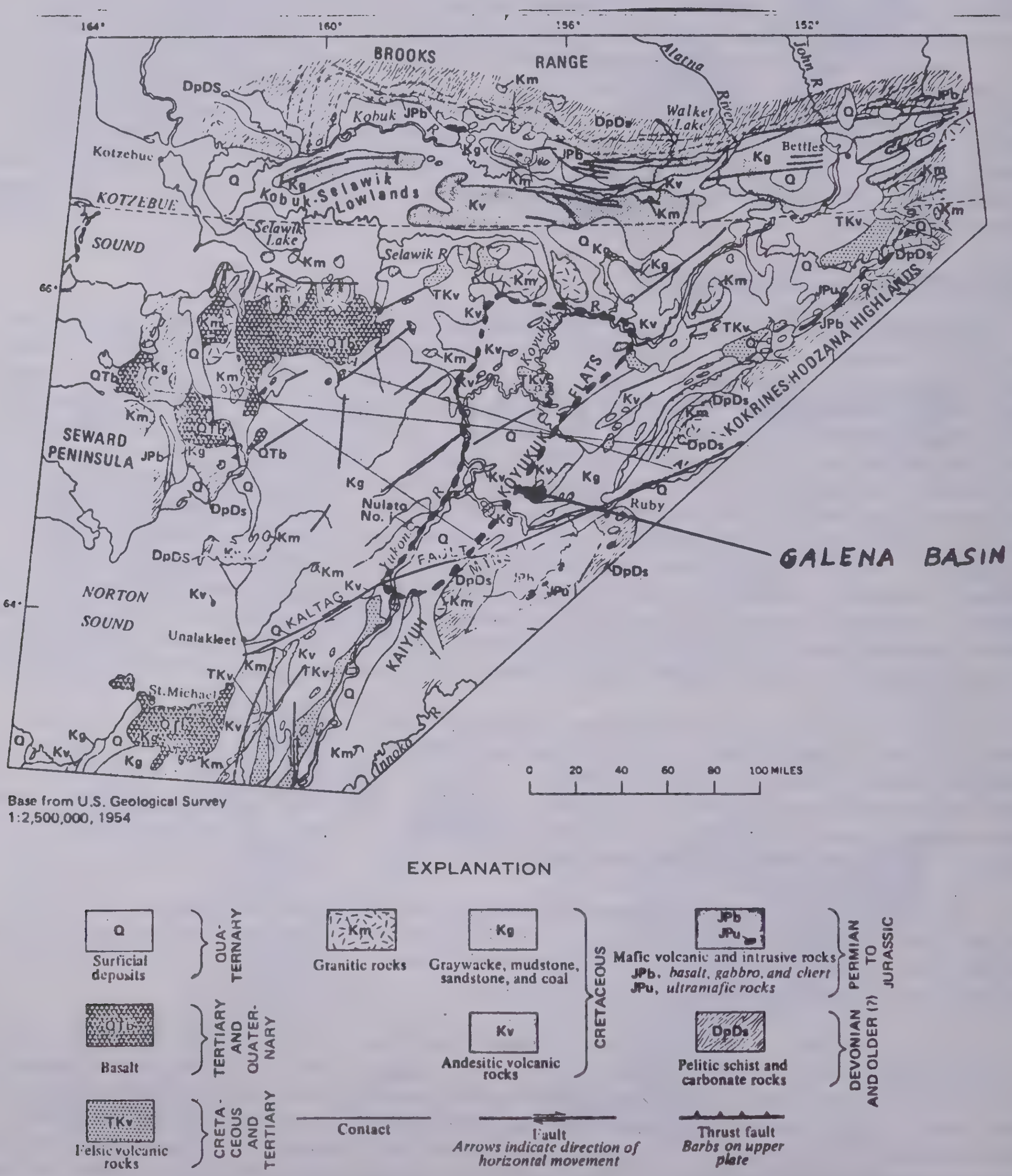


Figure 54. Reconnaissance geologic map of the northern Yukon-Koyukuk province. (Source: Patton, Jr., 1973.)

The generalized stratigraphic chart (fig. 53) and reconnaissance geologic map (fig. 54) were constructed by Patton and provide the basis for the discussion of the Galena Basin.

PERIOD OR EPOCH	STRATIGRAPHIC UNITS		LOCAL STRATIGRAPHIC NAMES		
Quaternary	Glacial drift, waterlaid and windblown silt deposits				
Quaternary and late Tertiary(?)	Basalt				
Early Tertiary and Late Cretaceous	Sand, gravel, clay, coal	Felsic volcanic rocks			
Late Cretaceous	Quartz conglomerate, sandstone, shale, and coal (nonmarine marginal trough deposits)				Bergman Group (abandoned) in upper Koyukuk R. region
Late Cretaceous and Early Cretaceous (Cenomanian and Albian)	Calcareous graywacke and mudstone in western part of province	Shallow marine and nonmarine sandstone, shale, conglomerate, tuff, and coal in eastern part of province	Kaltag and Nulato Formations of Yukon River Valley	Shaktolik Group (abandoned) in Norton Sound and Yukon R. region	
	Volcanic graywacke, conglomerate and mudstone		Ungalik Conglomerate in Norton Bay area		
Early Cretaceous (Neocomian)	Andesitic volcanic rocks		Koyukuk Group in Koyukuk River region		
Jurassic to Permian	Pillow basalt, diabase, gabbro, serpentinized peridotite and dunite, chert and slate				
Devonian and older(?)	Pelitic schist and carbonate rocks		Carbonate rocks included in Baird Group in southern Brooks Range		

Figure 53. Major stratigraphic units in northern Yukon-Koyukuk province and its borderlands. (Source: Patton, Jr., 1973.)

Pre-Cretaceous Rocks

Pre-Cretaceous rocks occur next to the Galena Basin only at the southeastern margin, in the Kaiyuh Mountains south of the Kaltag fault (fig. 54). These rocks are in a broad syncline where Devonian and older rocks lie on the east and west flanks, and Permian to Jurassic rocks are exposed between them. The Devonian and older rocks are chiefly pelitic schists and carbonate rocks, including quartz-mica schist, mica schist and phyllite, sometimes interbedded with carbonates. Limestone and dolomite are up to several thousand feet thick. Pennsylvania-Jurassic rocks appear to constitute a typical ophiolite suite, composed of pillow basalt, diabase, gabbro, chert, peridotite, and slate all of which have been altered to greenstones. Cass (1959) mapped these rocks and considered them possibly as old as Precambrian. The pre-Cretaceous rocks have been little studied, but they are recognized as a part of the broad crystalline complex which borders the Yukon-Koyukuk province on three sides.

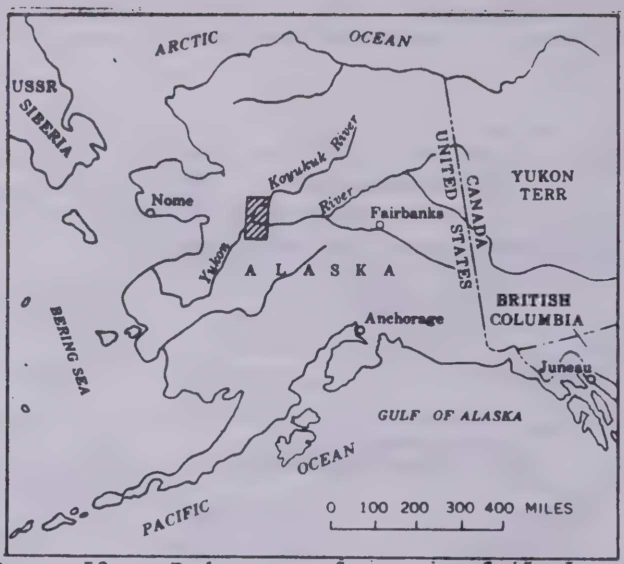


Figure 52a. Index map of a part of Alaska showing the location of the Yukon-Koyukuk Lowland. (Source: Weber and Pewe, 1961.)

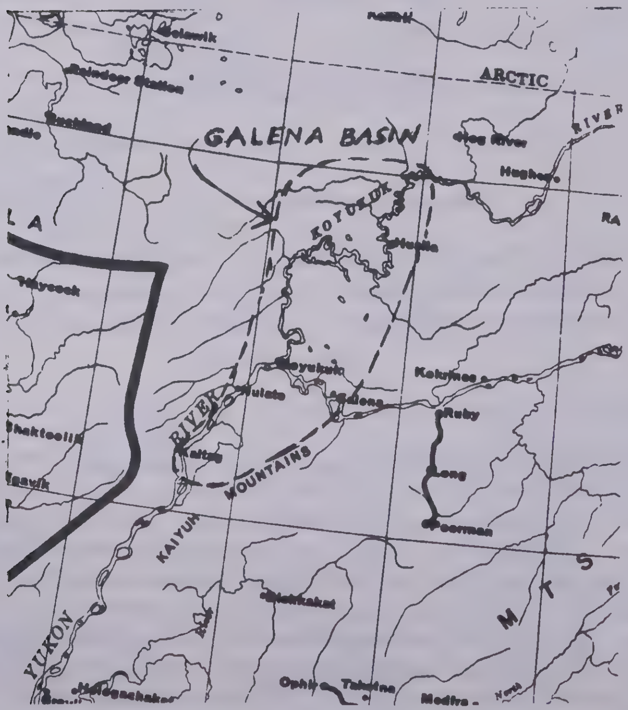


Figure 52b. Galena Basin location map.

irregular topographic low along the Yukon and Kuskokwim Rivers, which join in the southern part of the region (figs. 52a, b). The basin is covered by the USGS Nulato and Kateel River 1:250,000 topographic maps. The average width is about 40 miles.

The lowlands are dotted with thaw lakes, and the central parts next to the major rivers as seen from the air display in a spectactural way a broad complex of meander scars, oxbow lakes, swamps, and creeks (Weber and Pewe, 1961; p. D371-D373, 1970). Polygonal ground patterns and frost heaving are common. Two terraces, 30 feet and 250 feet above the flood plain, form distinct mappable features.

The lowlands are bounded on the north by the Purcell Mountains and the Zane Hills of the Hogatza uplift, on the east by the Kokrines Hills, on the southeast by the Kaiyuh Mountains, and on the west by a broad, low group of hills of the Chukotskiy—Seward Uplift, which extends from 80 to 120 miles westward to Norton Sound and Seward Peninsula. The hills, which immediately surround the lowlands, are 1,000 to 2,000 feet above the flood plain. The Kaiyuh Mountains are an isolated group 75 miles long and 15 miles in average width, separated from the Yukon River by about 25 miles of swamp lowland. The summits of the main ridge range from 2,000 to 3,000 feet above sea level. The Galena Basin is named after the village of Galena, which was established about 1919 on the Yukon River to supply lead prospectors south of the Yukon.

The climate is cold and semiarid. The average temperature at Nulato was earlier reported to be 22.4°F, and the average annual precipitation about 16 inches (Mertie, 1937, p. 151). The region in general is underlain by moderately thick to thin permafrost, except beneath the flood plains of the major rivers, which are areas of discontinuous permafrost. The area was not glaciated during Pleistocene time, but it has been subjected to alternating periods of great deposition and erosion. Vegetation consists of mosses, sedges, low brush, stunted black spruce, and rare birch. Bedrock exposures are generally poor.

Five native villages in the Galena Basin with populations from about 125 to 300 are located on the Yukon and the Koyukuk Rivers: Kaltag near the south end of the basin, Nulato 30 miles north of Kaltag, Koyukuk at the junction of the Yukon and the Koyukuk Rivers, Galena 25 miles east of Koyukuk on the Yukon, and Huslia, which is on the Koyukuk River in the northern part of the region. The villages have landing strips and are served by commercial aircraft.

The Galena Basin is near the center of a broad wedge-shaped feature called the Yukon-Koyukuk province (Patton, 1973) where thick Cretaceous and Tertiary terrigenous volcanic sediments accumulated over earliest Cretaceous marine andesites. The province is bordered on the west, north, and southeast by a metamorphic complex of predominantly Paleozoic age. It is a highly mobile region where repeated volcanism and plutonism occurred during Cretaceous and Tertiary times.

Sedimentary Rocks

Patton (1973), who has provided the most recent publication describing the geology of the region in which the Galena Basin lies, found that the earlier formation names applied in west-central Alaska were too vaguely defined for province-wide application and preferred not to use them in his stratigraphic descriptions.

Gulf-Alaska Port Heiden No. 1
S 20 T 37 S R 59 W. Logged 2,500-10,990 ft.

Pan American Hoodoo Lake No. 1
S 21 T 50 S R 76 W. Logged 100-8,050 ft.

No significant radioactive zones were noted on any of the logs.

Discussion

Thick Mesozoic sedimentary sequences on the Alaska Peninsula, consisting in part of nonmarine arkosic and tuffaceous sandstones with frequent carbonaceous zones, suggest the possibility of sedimentary-type uranium deposits in the region. The Naknek Formation in the northeastern part of the Peninsula is predominantly arkosic sandstone. The Staniukovich Formation in the Port Moller area also contains much feldspathic and arkosic sandstone. The Coal Valley Member of the Chignik Formation in the Chignik area is largely nonmarine and contains lignite beds and tuffaceous sandstones. Up to 30,000 feet of alternating marine and nonmarine Tertiary sediments contain much volcanic debris, carbonaceous material, and lignite beds and also invite study. Descriptions of the Tolstoi and Bear Lake Formations are encouraging for sedimentary-type uranium investigations.

Large granitic plutons of Tertiary age are present along the Alaska Peninsula, and the Cretaceous Aleutian Range batholith is at the head of the peninsula. In general, the intrusive rocks are not as alkalic as might be desired, but the north side of the Aleutian Range (Naknek) batholith is more alkalic than the southern side, and some syenite has been reported from near the lower end of Naknek Lake. Generally very little information is available on the plutonic rocks.

Conditions which seem unfavorable for the formation of uranium deposits on the Alaska Peninsula are:

1. Volcanic rocks are all basaltic and andesitic.
2. The region has been generally unstable throughout its history and the structure and stratigraphic relationships are complex.
3. There is relatively little known mineralization that suggests uranium associations.
4. The climate is very humid.
5. One theory states that magma of primary geosynclinal belts, including the Aleutian-Kamchatka arc, are not sufficiently differentiated to be important carriers of uranium and that the sediments in these regions accumulated too rapidly for syngenetic concentrations to form (Klepper and Wyant, 1956, p. 221).

It should be emphasized, however, that the Alaska Peninsula is still essentially uninvestigated for uranium, and that the nonmarine arkosic and carbonaceous sediments deserve consideration. Possibly the anomalous radioactivity found in the Chignik area by the Alaska Geological Survey may be significant.

THE GALENA BASIN

The Galena Basin, located in a west-central Alaska, extends 150 miles northeast from the village of Kaltag on the Yukon River to the Zane Hills on the north. Also known as the Koyukuk Flats and as the Yukon-Koyukuk lowland, the Galena Basin is an

Cretaceous sandstones, conglomerates, coal beds, and limestones of the Chignik and Herendeen formations were examined. The maximum radioactivity encountered was in a small lens of coal in the Chignik formation on the west coast of Port Moller Bay. This gave 2 1/2 times the average background count. The Staniukovich sandstone near a mineral spring and cabin, locally known as Hot Spring, gave a slight increase in count.

Radioactivity investigations were conducted in the vicinity of the old Apollo and Sitka mines on the southeast part of Unga Island. The two mines are situated within several hundred yards of each other. They were last worked in about 1912. Mineralization included gold, pyrite, galena, sphalerite, chalcopyrite, and native copper. The gangue is quartz, calcite, and orthoclase. The ore is in reticulated zones cutting andesite and dacite. The zones strike N 20° E and are nearly vertical. No radioactivity was detected. Geochemical soil sampling by the writer failed to indicate extensions of the veins.

Traverses along the north and northwest coasts of Unga Island revealed Tertiary sandstones, shales, and coal beds and an abundance of petrified wood, but no abnormal radioactivity. The lavas along the west coast of Popof were examined with negative results.

Coal has been mined at several points along the coast near Chignik, on Chignik Bay. Sediments examined in this area include the Jurassic Naknek Formation sandstones and the Cretaceous Chignik Formation sandstones, conglomerates, and coal beds. No anomalous radioactivity was found.

One day was spent investigating an old copper prospect on Warner Bay (Prospect Bay), which is on the coast due south of Chignik. There are two short tunnels in the Tertiary quartz diorite bluff near the shoreline on the north side of Warner Bay. Pyrite, chalcopyrite, galena, and molybdenite were seen on the surface in scattered pockets and on fracture surfaces. Only radioactivity considered normal for these rocks was encountered.

Additional testing for radioactivity was done by the State Division of Geological Surveys on the Alaska Peninsula during the 1974 field season. Numerous measurements were made with a portable scintillometer on outcrops in the Belkofski Bay, Chignik Lagoon, and Hoodoo Lake areas. Anomalous readings of between 2 and 3 times the average background of 60 cpm were obtained from outcrops of the Chignik and Belkofski Formation (W.M. Lyle, personal commun.) A report with maps showing the sample sites and radiometric values is soon to be published by the Division. Uranium analyses of samples collected in the field are planned.

The writer examined gamma-ray logs on the following wells drilled on the Alaska Peninsula:

Cities Service Oil Co., Panther Creek No. 1
S 14 T 35 S R 51 W. Logged 200-7870 ft.

was a northward-plunging shoot 5-40 feet wide and several hundred feet long. Workings consisted of shafts and extensive tunnels, one of which was more than 6,000 feet long. Major operations at the Apollo mine ended before World War I, but sporadic small-scale mining continued until World War II.

In 1908, lode claims were staked on Popof Island, where gold was discovered in intensely altered Tertiary andesite. The deposit, similar in many respects to the ones on Unga Island, is 5-10 feet thick and contains as much as an ounce of free gold per ton. A short adit and several shafts were driven, but there is no record of production.

Gold claims were also staked early in the century at Mallard Duck Bay and at the head of Port Moller. The Mallard Duck Bay deposit is in andesite and consists of breccia zones containing galena, sphalerite, pyrite, and quartz; the andesite wallrock carries abundant pyrite. The richest zone is 4-6 feet thick and at least 100 feet long. The Port Moller deposit is similar to the one at Mallard Duck Bay but is in basalt. There is no record of production from either deposit.

There are several copper lodes at Prospect Bay and on the east shore of Balboa Bay. The deposit at Prospect Bay consists of pyrite, sphalerite, and galena-bearing quartz veins in brecciated lava flows of probable Tertiary age. The metallic minerals occur in vugs, mainly in a zone 50 feet wide. The deposit at Balboa Bay consists chiefly of chalcopyrite in a shear zone in Tertiary volcanic rock. The properties were explored in the early 1900's by a few short adits, but no ore bodies were discovered and the claims were abandoned.

In 1920, samples of copper ore reportedly were taken from the mountain near the head of Puale Bay, where a lode said to consist of lenses of chalcopyrite reportedly was traced for a mile. Two samples from this lode assayed up to 0.31 ounce of gold and 8.1 ounces of silver per ton and 24.4 percent copper.

The Alaska Peninsula has not been very thoroughly prospected, and detailed programs may reveal commercial ore. Copper and molybdenum geochemical anomalies were found during a very cursuory investigation of the sulfur deposit near Stepovak Bay by the Alaska State Division of Geological Survey (Eakins, 1970).

Radioactivity Investigations

The only investigations for radioactivity on the Alaska Peninsula of which the writer is aware are those conducted by the State Division of Geological Survey. Apparently no investigations were made by the U.S. Geological Survey during the early Alaskan uranium studies.

The writer visited several areas on the peninsula during the summer of 1968. Some short traverses with portable Geiger counters were made (Eakins, 1969, p. 17 and table, p. 34-35). The results are reproduced below:

Foot traverses were made along the coast around Port Moller Bay and inland on the peninsula between Port Moller Bay and Herendeen Bay and across Staniukovich Mountain. Sandstones, conglomerates, and volcanics of the Tertiary Bear Lake and Tolstoi formations and the

Oil and gas seeps are known in Middle and Upper Jurassic rocks, and beds containing petroleum residue or yielding a petroliferous odor have been reported in Upper Triassic, Lower Jurassic, and Upper Cretaceous rocks (Gates, Grantz, and Patton, 1968, p. 22). Twelve test wells (many shallow) were drilled near Kanatak north of Wide Bay. Other exploration wells drilled at scattered locations more recently have penetrated to depths of more than 14,000 feet. Large anticlinal structures offer drilling targets, but the porosities in the Mesozoic rocks have been found to be very low. More porous Tertiary sandstones overlying Mesozoic source rocks might create a petroleum reservoir. Exploration both on the peninsula and in the adjacent Bristol Bay region is continuing.

Coal is present in significant amounts in three areas on the Alaska Peninsula: Herendeen Bay, Unga Island, and the Chignik area. A little coal was mined underground in these areas during the early part of the century. The Unga field contains Tertiary lignite only; the other two fields contain both Cretaceous bituminous coal and Tertiary lignite (Atwood, 1911, p. 96-124; Barnes, 1967, p. B28-B29).

Coal-bearing rocks of the Late Cretaceous Chignik Formation underlie at least 40 square miles on the peninsula between Herendeen Bay and Port Moller, and the Tertiary lignite-bearing beds extend over several hundred square miles, mostly south and east of Herendeen Bay. The Tertiary beds do not seem to be important, but the Cretaceous coal occurs in a large number of closely spaced beds ranging from a few inches to 7 feet thick.

Tertiary lignite-bearing beds underlie about 40 square miles in the northern part of Unga Island. Nearly 300 feet of poorly consolidated sediments with interbedded lignite beds up to 4 feet thick have been measured. These beds dip 8°-10° W.

The Late Cretaceous Chignik coal field is on the west shore of Chignik Bay in a belt 25 miles long by 1 to 3 miles wide. Coal beds are up to 5 feet thick and are moderately folded.

Sulfur deposits, some with commercial possibilities, are associated with volcanoes and fumeroles on the Alaska Peninsula and the Aleutian Islands. Occurrences at four areas have been investigated: near Stepovak Bay on the peninsula, on Akun Island, at Makushin Volcano on Unalaska Island, and on Little Sitkin Island (Drews and others, 1961, p. 657; Eakins, 1970; Maddren, 1917; and Snyder, 1959, p. 205-206).

Few metalliferous deposits have been found on the Alaska Peninsula; and only the mines of Unga Island have had any recorded lode production. The following summary of the mineral deposit on the Alaska Peninsula is taken from Berg and Cobb (1967, p. 5-7):

> *Lodes containing gold, silver, copper, lead, and zinc occur in the Alaska Peninsula region. The most important are on Unga Island where about $2 million, chiefly in gold and silver, was produced between 1891 and 1904, mainly from the Apollo mine. The Apollo ore body, a reticulate network of mineralized fractures in intensely altered (prophylitized) andesite and dacite of Tertiary age, consisted of free gold, pyrite, galena, sphalerite, chalcopyrite, and native copper in a gangue of quartz and subordinate calcite and feldspar. Comb structure and crystal druses indicate that the minerals were deposited in open spaces at relatively shallow depths. The main ore body, which averaged about 0.4 ounce of gold per ton,*

A large batholith is located between Wide Bay and Chiginagak Bay. It is similar in age and composition to the other coastal batholiths. Another large pluton described as "granite and diorite" is exposed at Cape Douglas next to Kamishak Bay at the head of the peninsula.

Burk (1965, p. 112) makes a footnote reference to a report by Dall and Harris (1892, p. 239) stating that Chiachi Island, east of Stepovak Bay, contains "syenite unconformably overlain in places by sandstones and conglomerates." Some syenite and arkoses were also reported at the lower end of Naknek Lake (Atwood, 1911, p. 31).

A characteristic of the mid-Tertiary plutons that distinguishes them from the early Tertiary bodies is the abundance of magnetite as an accessory mineral and as magnetite deposits in contact zones.

Structure

All the prominent structural features of the Alaska Peninsula were formed by post-Miocene deformation, and during Pliocene time the orogenic mountain system developed. The general strike of the rocks is northeast parallel to the continental margin. The continental margin on the south side of the peninsula, the Shumagin-Kodiak shelf, seems to have had a history different than that of the Alaska Peninsula mainland but the exact nature of the boundary between the two features is not well understood. The Shumagin-Kodiak shelf consists of a thick flysch sequence that has been intruded by Tertiary plutons.

The major structural features of the Alaska Peninsula have been mapped by Burk (1965, part 3). North of Wide Bay, the dominant feature is the Bruin Bay fault, which separates the Jurassic Aleutian Range (Naknek) batholith on the north side from Jurassic sediments on the south side. South of Wide Bay, large northeast-trending anticlines with tight accessory folds are the principal structures. Three major anticlines include the one in the Wide Bay-Aniakchak area, the one in the Chignik-Stepovak Bay area, and the one in the Port Moller-Pavlof Bay area. Fault displacements in the basement rocks may control the origin and shapes of the folds. Attitudes of the bedding vary from nearly flat (in the relatively undisturbed area) to vertical (next to faults zones and intrusive rocks). These anticlines along the Alaska Peninsula are possible petroleum reservoirs.

Faults have been grouped into three catagories by Burk (1965, p. 131-132): (1) faults associated with the large anticlines, (2) faults unrelated to such folding, represented by the Bruin Bay fault, and (3) the large parallel faults of the Shumagin-Kodiak shelf. The first group includes high-angle reverse faults that are common to the peninsula; these generally dip northwest and mark the south borders of the large anticlinal complexes. No major strike-slip faults are known in the region.

Economic Geology

The resource of the Alaska Peninsula that has received the most interest for many years is petroleum. The petroleum industry has conducted geological and geophysical surveys and drilled a number of exploratory wells. Attention was brought to the region by oil seeps as early as 1902. A small oil boom took place in the vicinity of Cold Bay during 1903 and 1904; shows of oil and gas were found but no production was achieved (Capps, 1923, p. 77-116).

The depocenter on the northwest side of the peninsula has been called the Becharof basin, which may contain a thick Tertiary section and extend as far south as Port Moller (Gates and Gryc, 1963, p. 275).

Igneous Rocks

Paleozoic

The oldest igneous rocks known on the Alaska Peninsula are the Permian volcanic debris at Puale Bay. Volcanism apparently continued intermittently into the Late Triassic. All the extrusive rocks of the period were basalts and andesites.

Mesozoic

Plutonic rocks of Mesozoic age are known to be associated only with the Aleutian Range (Naknek Lake) batholith at the head of the peninsula. The batholith lies along the north side of the Bruin Bay fault, northwest of Katmai National Monument. Debris from the pluton is found in the Tuxedni Formation in the Cook Inlet region and as arkose in the Upper Jurassic to Lower Cretaceous sequence on the Alaska Peninsula. The wide distribution of arkose suggests that other plutonic rocks may possibly be buried beneath the lowlands of the peninsula that border the Bering Sea.

Cenozoic

Volcanism during Tertiary and Recent times has been summarized by Burk (1965, p. 107-108). Early Tertiary was a time of extensive volcanism throughout the Alaska Peninsula, and volcanic debris constitute most of the Paleogene strata. About 25 volcanoes are present on the peninsula and more than a dozen of these are active or have been active in recent times (Coats, 1950). Flows and breccias of Miocene and Pliocene ages are especially widespread, and prominent volcanic peaks can be seen at intervals along the backbone of the peninsula. Dikes and sills have intruded rocks of all ages.

Tertiary plutons of the Alaska Peninsula occur along two trends of different ages (Burk, 1965, p. 108-110, and fig. 18). The earliest trend lies on the continental shelf off the Alaska mainland and includes part of Kodiak Island, the Semidi Islands, and the Shumagin Island group. Later mid-Tertiary batholiths intruded Paleozoic and older rocks along the Pacific shore. These batholiths are quartz diorite to quartz monzonite, but only a few very generalized petrographic descriptions are available.

The batholith exposed in parts of the Shumagin Island group is 30 miles in diameter and reaches to near the edge of the continental shelf. Limited thin-section studies indicate a quartz monzonite approaching a granodiorite. Three potassium-argon ages on the batholith range from 56 to 64 m.y. The plutonic rocks of the Sanak Islands are similar to those of the Shumagin Islands.

A cluster of quartz diorite stocks is exposed along the Pacific shore in the mountains near Belkofski at the lower end of the peninsula. These plutons are probably mid-Tertiary. The rocks contain up to 20 percent quartz, 60 percent andesine plagioclase, and 20 percent hornblende, biotite, and magnetite.

Approximately 150 miles northeast of the stocks at Belkofski Bay, plutons of quartz diorite to diorite occur at Kuiukta Bay and on the nearby islands. These plutonic rocks intrude the lower Tertiary Beaver Bay Group.

The Beaver Bay Group in the Cold Bay area included the Belkofski Formation and stratigraphic equivalents to the Stepovak Formation. The Belkofski Formation consists of at least 6,000 feet of fine- to coarse-grained sandstone, conglomerate, and breccias composed of mafic volcanic debris. A 200-foot-thick bed of "green arkose" at the base of the formation was reported on the crest of an anticline between Pavlof Bay and Cold Bay.

Following deposition of the Stepovak Formation and Bear Lake Group, a transition period developed between Oligocene and Miocene. This was a time of uplift, erosion, and deformation on the peninsula. Unconformably above the Stepovak Formation and Beaver Bay Group is the Miocene Bear Lake Formation, which consists of 5,000 feet or more of nonmarine sandstone and conglomerate high in volcanic material and nonvolcanic debris and is widespread on the peninsula. The sandstone commonly contains more than one-third quartz and chert, about one-third sedimentary lithic fragments, and less than one-third volcanic fragments. Most of the sandstones are classified as subgraywackes. These sediments differ from all earlier Tertiary deposits in greater rounding and sorting of the grains and less overall compaction. The upper part of the formation locally contains an abundance of marine invertebrates; the lower part is less fossiliferous. The Bear Lake Formation type section is near Bear Lake in the Port Moller area.

Coarse beds of conglomerate on Unga and Popof Islands contain marine mollusks and plants, and are up to 800 feet thick. The unit is named the Unga Conglomerate Member of the Bear Lake Formation. The lower half contains friable sandstones, conglomerates, and thin coal seams. Coal-bearing Eocene and Miocene beds are thought to underlie 35-40 square miles near Zachary Bay at the north end of Unga Island, where a 200-foot section of sandstone, conglomerate, tuff, clay, and lignite was measured (Atwood, 1911, pg. 117-118). Tertiary sediments are also present on Andronica Island at the Haystacks. The upper half of the Unga Conglomerate consists of rounded clasts of volcanic rocks up to 1 foot in diameter, with some sandstone beds. Equivalent strata have been identified as a basal part of the Bear Lake Formation on the Alaska Peninsula mainland at several localities. Many large silicified *Sequoia* or *Metasequoia* tree stumps and logs are exposed in the Unga Conglomerate or have eroded out of the bluffs along the northwest shore of Unga Island (Eakins, 1970).

Pliocene volcanic and marine clastic rocks unconformably overlie the Bear Lake Formation. In the Cold Bay area, several hundred of feet of Pliocene marine sandstone, conglomerate, and some shales have been named the Tachilni Formation. Volcanic material and chert constitute most of the sand grains and conglomeratic clasts. The rocks are poorly consolidated and locally very fossiliferous. Sandstones and conglomerates in the Herendeen Bay area are also believed to be Pliocene in age. These beds are yellow to light gray, cross bedded to evenly bedded, and contain slightly carbonized wood.

The northern side of the Alaska Peninsula adjacent to Bristol Bay is a flat, marshy, tundra-covered region which, for petroleum exploration purposes, may be considered a part of the Bristol Bay depression. Volcanic materials from the Alaska Peninsula have been deposited here, but the character of the rocks and their potential for sedimentary uranium deposits are not known to the writer. Bristol Bay is a potential petroleum province where considerable subsurface work has been done by petroleum companies, but the information acquired is not available. The lowlands along the upper part of the Alaska Peninsula are named the Bristol Bay Lowlands, and those along the lower part of the peninsula are the Bering Sea Lowlands.

Cass (1959) mapped a number of Tertiary or Cretaceous plutons that intrude the Paleozoic metamorphic complex in the Kaiyuh Mountains. The largest intrusive body, which forms part of Khotol Mountain, is next to the Galena Basin lowland. It is about 15 miles long and up to 6 miles wide. Smaller intrusive bodies intrude the metamorphosed igneous rocks in the central part of the broad synclinal structure in this area. They were simply named "granite and diorite." Intrusive rocks of Cretaceous or Tertiary age in this area include numerous unmapped dikes of varying composition and texture.

Mertie (1937, p. 170) reported a granitic body on a spur near the head of Kluklaklatna (Little Mud) River in the Kaiyuh Mountains. The outcrop consists of weathered rubble. The rock, which Mertie thought could not be more basic than granodiorite, is composed of quartz, plagioclase, microcline, and biotite.

In the Kokrines Hills on the northeast side of the Galena Basin, the plutonic rocks are of two ages: the older, the Paleozoic or Mesozoic batholith, which lies east of the Melozitna River; and the younger, which consists of several Tertiary plutons on the west side (Eakin, 1916, pl. II). The large granitic body east of the Melozitna River trends northeast from Ruby on the Yukon and extends 40 miles into the Ray Mountains. It is up to 20 miles wide. The batholith has not been mapped in detail, but has been found to have a considerable range in composition. The most common rock is biotite granite, with monzonite and diorite. The massive parts are coarse-grained to unusually coarse porphyritic with feldspar crystals as long as 3 to 6 inches. Some of the granite is sheared.

The younger Tertiary granites, west of the Melozitna River, also have a great range in composition and texture. Eakin mapped three bodies which are up to 12 miles long and 3 miles wide. The dominant variety was described as a medium-grained equigranular normal granite, but variations include pegmatite and aplite in which dark minerals are almost absent. Some phases approach a diorite.

It is difficult to speculate on how much the plutons have contributed to the sediments of the Galena Basin, but the biotite granite and monzonite intrusive rocks show differentiation, and are coarsely porphyritic, similar to the rock types known to be uranium bearing in other regions.

Structure

All the pre-Tertiary rocks of the northern Yukon-Koyukuk province are intensely deformed and characterized by steep dips, tight folds, and high-angle faults (Patton, 1973, p. A14). The broad structural high of the Hogatza plutonic belt north of the Galena Basin has an east-west alignment. East and west of the basin the folds and faults trend generally northeast.

A major regional fault, the Kaltag fault, has been traced for 275 miles across west-central Alaska from Norton Sound to near the mouth of the Tanana River (Patton and Hoare, 1968). The Kaltag fault crosses the southern part of the Galena Basin on a strike of N 20° E. Displacement of geological province boundaries and trends appears to be 40 to 80 miles right laterally. Movement seems to have occurred before mid-Tertiary time and to have continued into Holocene time.

Economic Geology

The one exploratory well drilled for petroleum in the Galena Basin was the Benedum et al. No. 1 Nulato Unit, completed in 1960. The well was spudded in Cretaceous rocks on the west border of the basin and did not penetrate the sediments in the central part of the lowland. The hole reached a depth of 12,015 feet and presumably was still in Cretaceous rock. No shows of oil or gas were reported.

The following sample descriptions are summarized from the Nulato No. 1 drilling report:

Depth (ft)	Lithology
598-1,213	Cretaceous shales and siltstones.
458-4,600	Silty sandstone, dark gray, hard, tight. Partly micaceous.
5,035-5,370	Siltstone, dark gray, hard, tight, sandy, micaceous.
5,370-5,460	Sandstone, medium gray, angular, hard, tight.
5,460-5,490	Siltstone, dark gray, pyritic, shaley, hard.
5,490-6,675	Shale and siltstone, partly micaceous, and pyritic beds. Milky quartz veins from 6,380-6,675 ft.
6,675-7,840	Siltstone, medium gray, micaceous; some hard dark-gray to black shale.
7,840-8,080	Shale, dark gray, silty, hard, micaceous.
8,080-8,423	Silty shale, dark gray, fractured, micaceous.
8,423-8,760	Siltstone, medium gray, angular, sandy, hard, tight. Traces of vein quartz and calcite.
8,760-10,170	Siltstone, light to medium gray, hard, tight, micaceous, pyritic, some quartz, calcite, and black shale.
10,170-10,665	Sandstone, light to medium gray, very fine to medium grained, angular, calcareous, hard, tight, quartzitic.
10,665-11,104	Covered. Recovered sandstone. Medium gray, quartzitic, fine grained; hard, micaceous, with interbedded dark gray, hard, splintery shale.
11,104-12,015	Interbedded and interlaminated sandstone, siltstone and shale, all hard, tight, micaceous.

The only placer mining in the Kaiyuh district was at Camp Creek at the site of the abandoned village of Tlatskokot, where a small amount of gold was recovered immediately after World War II. The deposit must have been limited, as no activity was reported in later years.

A small group of silver-lead deposits called the Perseverence and Valley claims are at the northeastern end of the Kaiyuh Mountains, about 27 miles south of Galena. The deposits are in quartz-mica schist and consist of argentiferous galena veins as much as 3 feet thick that strike northeastward parallel to the foliation. About 175 tons of ore averaging 73 percent lead and 104 ounces of silver to the ton were shipped, but operations were discontinued in 1922 because of high transportation costs (Berg and Cobb, 1967, p. 228).

Hematite in thin beds, 3 inches to 3 feet thick, occur in a lower greenstone sequence near the Yuki (or Yuko) River that drains eastward from the central parts of the Kaiyuh Mountains (Mertie, 1937, p. 162-163). The beds are probably volcanic clastics as they are interbedded with a lava and tuff. In places the red beds alternate with green beds.

Other known metalliferous deposits are considerable distances from the Galena Basin. Traces of zinc, gold, and other metals have been found at Red Mountain Creek, about 25 miles north of Hughes on the upper Koyukuk River. A molybdenum lode has been prospected near Indian River a few miles west of Hughes (Berg and Cobb, 1967, p. 226).

The Ruby-Long-Poorman placer district extends south from the Yukon River for 50 miles. Placer gold production centered at Ruby, Long, and Poorman was significant during the early 1900's. Although mineralized bedrock probably occurs at many places in the district, the only lode that has been described is a silver-lead deposit in schist, slate, and chert on Beaver Creek, about 14 miles south of Ruby. The ore contains galena, silver, cerussite, and limonite. No ore has been shipped. Heavy minerals from placers contain gold, cassiterite, scheelite, galena, cinnabar, stibnite, and bismuth (Hardner and Reed, 1945, p. 21).

Mineralization in the Zane Hills and Purcell Mountains north of the Galena Basin has been discussed in the section of this report on the "Alkaline Intrusive Belt of West-Central Alaska and the Selawik Basin Area." Placer gold was produced for many years from Bear Creek, and traces of tin, platinum, zinc, molybdenum, silver, bismuth, copper, and uranium have been found in the Zane Hills. Placer gold was produced from Shovel Creek in the Purcell Mountains.

A little coal was reported on the Yukon River near Louden, 10 miles southeast of Galena (Mertie, 1936, p. 136). Thin coal beds associated with sandstone, shale, and conglomerate are probably of Eocene age.

Radioactivity Investigations

There are no published reports of uranium investigations having been conducted within the Galena Basin proper. The results of studies within the general region will, however, be discussed.

White, Stevens, and Matzko (1963, p. 86-87, Table 7) gave the following report on a radiometric traverse along the Yukon River between Tanana and Ruby:

> *Sedimentary rocks of Cretaceous age are exposed in the Melozitna River Canyon. Radiometric tests on conglomerate, sandstone, grit, black shale, and limestone in this area indicated about three times the radioactivity of other rock types tested farther upstream on the Yukon River. The grit gave the maximum reading in the field, but tests made in the laboratory show a low radioactivity content (maximum of 0.017 percent eU) for all the various rock types examined.*

White and Stevens (1953, p. 3-9) made their own report on radioactivity in the Ruby-Poorman area. Fifteen placer concentrates from Ruby, Glacier, and Big Creeks south and east of Ruby tested from 0.000 to 0.006 percent eU.

In the Long area, 47 placer concentrates from several creeks east of Long were tested (White and Stevens, 1953, p. 3-9). Values ranged from 0.000 to 0.43 percent eU. Granitic rock from the same areas contained from 0.003 to 0.006 percent eU and averaged 0.005 percent. The heavy-mineral fraction of the granite ranged from 0.007 to 0.036 percent eU. Heavy-mineral fractions of panned concentrates from placers and disintergrated granite in the vicinity of Birch Creek contained from 0.007 to 0.36 percent eU, but the Birch Creek material was more highly concentrated than that of the other samples.

Concentrated material from a granitic area on Flint Creek ranged from 0.015 to 0.15 percent eU and averaged 0.037 percent. The granite on upper Flint Creek is apparently somewhat anomalous in radioactivity, due chiefly to a uraniferous thorium silicate, tentatively identified as uranothorite. The heavy fractions also contained much sphene, allanite, and zircon, which contributed to the total radioactivity of the samples. A highly concentrated (3,800:1) fraction of a sample from Flint Creek yielded a value of 1.63 percent eU. A spectrographic analysis of selected grains from this sample produced over 10 percent thorium and silicon, 0.1 to 1.0 percent bismuth, some cobalt, iron, and tin, and eight other metals in the 0.01 to 0.1 percent range. Other mineral concentrates from Monument and Flint Creeks produced 0.032 and 0.43 percent eU. These samples contained a green uraniferous thorium-yttrium silicate, possibly uranothorite.

South of Poorman, three concentrated samples of granitic material from Solomon Creek ranged from 0.002 to 0.056 percent eU, but the bedrock source of the material was not located.

The investigators of the Ruby-Long district concluded that the area did not contain commercial deposits of uranium, but they noted that very little bedrock is exposed, and that the cover material would mask any radioactivity. Modern techniques and equipment might locate the source areas for the radioactive minerals in the stream concentrates and possibly significant deposits within the granitic rocks of the district.

Discussion

There is little information upon which to evaluate the sediments in the central portion of the Galena Basin, and the presence of Tertiary beds so far has not been determined. Further field work and drilling are needed to assess the possibility of uranium-bearing sediments in the lowlands. Lode deposits in the general region, while not abundant, include metals that are favorable for uranium association: i.e. lead, silver, molybdenum, and bismuth. The nonmarine Cretaceous unit west of the Galena Basin as mapped by Patton (1966) has some uranium host-rock characteristics (despite being highly deformed).

Tertiary or Cretaceous granitic plutons that intrude metamorphosed Paleozoic igneous rocks in the Kaiyuh Mountains may have been magmatically differentiated enough to have high uranium contents, but this is speculation.

The sandstones and coal-bearing rocks near Louden, 10 miles southeast of Galena, and the Cretaceous sediments in the Melozitna canyon area, especially the "grit" that yielded an eU of 0.017 percent, seem to warrant checking.

The granitic rocks in the Ruby-Long placer gold district contain radioactive accessory minerals, and traces of uranothorite have been identified. The bedrock of the district is almost totally covered, so that past investigations were very restricted. Geochemical prospecting methods might locate anomalies in the granites worthy of drilling.

TERTIARY DEPOSITS AND GRANITIC ROCKS OF THE EAGLE-CIRCLE DISTRICT

A belt of nonmarine sedimentary rocks of Upper Cretaceous to Pliocene(?) age lies along the south side of the Yukon River from the international boundary to Woodchopper and Webber Creeks, which are east of Circle (fig. 56). The Upper

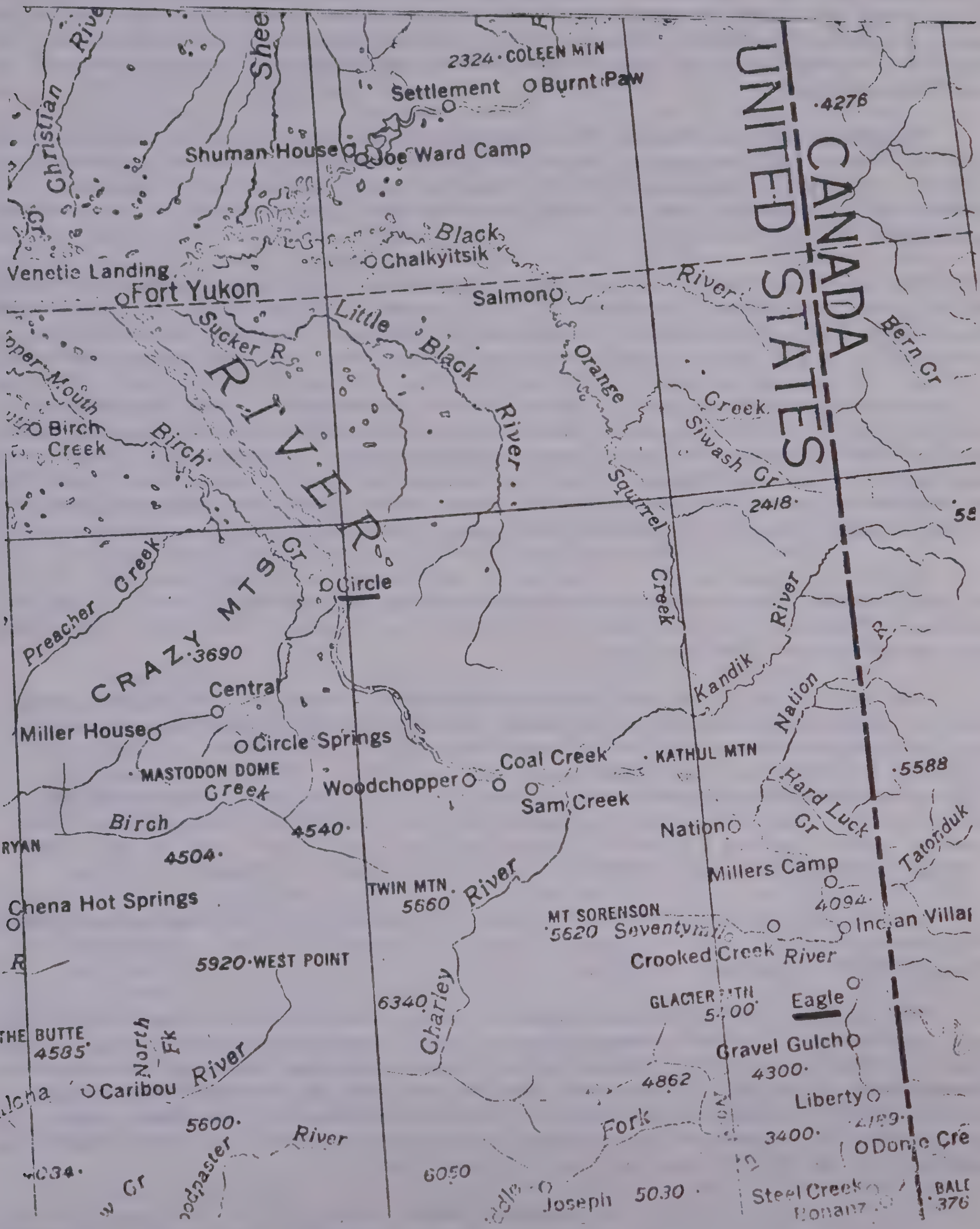


Figure 56. Index map of the Eagle-Circle district. Scale 1:584,000.

Cretaceous Tertiary sediments lie within a few miles of (and are topographically lower than) the large, Mesozoic, granitic Charley River batholith to the south, which presents a favorable situation for the accumulation of sedimentary-type uranium. The sediments of the belt are within the 1:250,000 Charley River and Eagle quadrangles.

The geology of the Charley River quadrangle has been mapped by Brabb and Churkin (1969), and the geology of the Eagle quadrangle was compiled by Foster (1972). The Upper Cretaceous Tertiary deposits of the Eagle-Circle area were specifically studied by Mertie (1942), who also published a report on the general geology of the region (1930).

The Upper Cretaceous Tertiary belt occupies a trough formed along the Tintina fault zone (or Tintina Trench), which is an extension of the Rocky Mountain Trench and a major structural feature in east-central Alaska. The fault zone is also referred to as the Eagle Trough. The area underlain by Upper Cretaceous Tertiary sediments along the trough is from 2 to 15 miles wide and 80 miles long. The area is one of low, rounded ridges, which continues northwestward along the Yukon River Valley into the loess-covered terraces and lake-dotted plain of the southeastern part of the Yukon Flats. The hills are heavily wooded. South of the trough area, mountains of the Yukon-Tanana Upland rise gradually to altitudes of over 5,000 feet. On the north side of the trough and the Yukon River, the Ogilvie Mountains form a rather rugged group with a maximum altitude of about 4,600 feet.

The Yukon-Tanana Upland is drained by north-flowing streams that rise in the highland to the south and have superimposed courses to the Yukon River in narrow valleys. The major tributaries to the Yukon River on the north side of the trough are the Nation and Kandik Rivers.

The town of Eagle, on the Yukon, is near the southeastern end of the trough and is accessible by the Taylor Highway. The northwestern end of the trough is near Woodchopper Creek, which is a south tributary of the Yukon. A short road connects the lower parts of Woodchopper and Coal Creeks. Circle is located a little farther downstream on the Yukon and is accessible by the Steese Highway. Other parts of the area can be reached by boat on the Yukon River and its tributaries. Short landing fields are located at Eagle and Circle, and at one time landing strips were used at the Nation and Woodchopper settlements.

The climate is similar to that of the Fairbanks area. The yearly mean annual temperature is 25°F, and the average precipitation is 10 inches. Permafrost is discontinuous throughout the area.

The Tertiary and Cretaceous sediments in the trough are in a synclinal belt and they probably are in sedimentary contact with both the metamorphic-age granitic rocks of the Yukon-Tanana Upland on the south and the highly indurated Precambrian, Paleozoic, and Mesozoic sediments of the Ogilvie Mountains on the north. While the Tertiary belt closely follows the source of the Yukon River, the contacts are separated by a narrow belt belonging to the Precambrian-Tertiary sequence of the Ogilvie Mountains or the Kandik Basin.

Sedimentary Rocks

A large number of geological formations and groups ranging in age from Precambrian through Tertiary have been mapped in the area (Brabb and Churkin, 1969;

Foster, 1972). The north side of the trough and Tintina Trench is occupied by one of the most complete stratigraphic sections in Alaska. The area north of the Yukon River is termed the Kandik Basin. The pre-Tertiary rocks south of the Tintina fault do not correlate with those on the north side because of the great right-lateral displacement along the Tintina fault, which may be as great as 260 miles (Davies, 1972). The rocks on the south side of the trough are mostly metamorphosed sediments and greenstones of Paleozoic age and Mesozoic granitic rocks. The present section of this report is concerned principally with the Upper Cretaceous Tertiary rocks and is limited mostly to their descriptions. Descriptions of most older rocks do not seem to suggest that they would be favorable hosts for uranium. However, one older sedimentary formation that may possibly be of interest to uranium explorationists is the Nation River Formation, which is exposed on both sides of the Yukon River from a short distance downstream from Eagle to about 6 miles below the mouth of the Nation River. Early reports dated the Nation River Formation as probably Permian, but Brabb and Churkin (1967) have shown that it is most likely Late Devonian.

The Nation River Formation consists of up to 4,000 feet of nonmarine clay shale, sandstone, and conglomerate which has been said to resemble Tertiary sediments. This type locality is on the north side of the Yukon below Nation River. The formation was described by Mertie (1930, p. 113) as a drab, sandy, clay shale and sandstone with dark conglomeratic beds. The conglomerate beds are composed of chert pebbles set in a sandy matrix and are up to 60 feet thick. Bituminous coal has been mined from the Nation River Formation at Nation River.

The Nation River Formation was described by Brabb and Churkin (1969) as follows:

> *Rhythmically interbedded, mudstone, sandstone, gritstone, and conglomerate. Graded beds common. Mudstone is olive gray and nearly everywhere contains plant fragments and spores of Late Devonian age. Sandstone is olive-gray, chert-quartz arenite and wacke, commonly with carbonate cement. Gritstone and conglomerate composed mostly of varicolored chert granules and pebbles. Thickness approximately 2,000 to 4,000 feet.*

The beds of the Nation River Formation are folded, in places rather closely. It seems that the characteristics of the formation favoring uranium are that the formation is nonmarine and contains feldspar and carbonaceous material.

The study of the Upper Cretaceous-Tertiary sediments in the Eagle-Circle district by Mertie (1942) was primarily for determining the source of the placer gold which was mined from streams south of the Yukon River, most notably at American, Coal, Woodchopper, and Fourth of July Creeks. Mertie's conclusion was that the immediate source of the gold was the Upper Cretaceous-Tertiary sandstones and conglomerates but the original source was the granitic rocks to the south. The Upper Cretaceous-Tertiary sediments were probably laid down in an alluvial basin which was originally much more extensive than it is today.

Outcrops of the Upper Cretaceous-Tertiary rocks are not extensive because they are generally little indurated and nonresistant to weathering, though some units are locally well indurated. Exposures can be found in stream valleys. However, no complete section is exposed anywhere and partial sections have not been combined to yield a composite section. The following section of Upper

Cretaceous-Tertiary rocks was measured in the Seventymile River area (Mertie, 1942, p. 231):

Section of Tertiary rocks in the valley of Bryant Creek

	Feet
Sandstone. Strike N. 85° W.; dip 80° S	*50*
Covered	*300*
Conglomerate, with 2 thin beds of sandstone	*75*
Greatly sheared black carbonaceous shale	*50*
Mainly conglomerate, with some sandstone. Strike N. 80° E.; dip 80° S	*20*
Covered in part, but in part conglomerate. Strike N. 85° E.; dip 90° S	*300*
Black shale, with some thin-bedded sandstone	*40*
Conglomerate	*10*
For the most part covered, but with occasional outcrops of conglomerate	*1,050*
Covered	*180*
Conglomerate	*20*
Shaly sandstone, with several beds of very carbonaceous shale about 6 inches thick. Some of these approach closely in composition to bony coal	*40*
Conglomerate and sandstone	*50*
Covered	*300*
Conglomerate	*20*
Covered	*1,200*
Intermittent exposures of sandstone and conglomerate. Strike N. 65° W.; dip 30° NE	*80*

Generalized descriptions of the lithologies are taken from Mertie (1942, p. 224-225):

The materials composing the Tertiary conglomeratic rocks and sandstones tend to be fairly uniform in lithologic character, but at some localities where these rocks lie close to the underlying Paleozoic and Mesozoic rocks their composition varies markedly from the usual composition. At most places the pebbles of the conglomeratic rocks consist of chert of various colors, quartzite, and vein quartz, which are the types of rocks that are practically indestructible, except by abrasion. Locally, and especially near the base of the formation, pebbles and cobbles of granitic rocks, greenstone, schist, argillite, and even limestone have been observed. In most of the conglomeratic rocks, the pebbles are relatively small, the maximum diameter being 4 or 5 inches and the average between 1 and 2 inches. But at certain horizons near the base of the sequence, coarse conglomerate has been observed, as for example on American and Crooked Creeks. The best example of coarse conglomerate, however, is along the ridge that separates Crooked Creek from Trout Creek. Here large residual cobbles and boulders of quartzite as much as 2 feet or more in diameter lie at the surface and represent the debris derived from the surficial alteration or slaking of coarse conglomerate. The

sandstones of the series are not materially different from the conglomerates, except for the smaller size of the component grains. Under the microscope the finer rock-forming minerals, both of the conglomerates and sandstones, are found to be quartz, orthoclase, plagioclase, hornblende, and mica, together with iron ores, zircon, garnet, and other heavy minerals derived from granitic rocks and crystalline schists. At places the heavy minerals are concentrated in stratified layers and in general appear to be more plentiful than in their origin parent rocks. Most of the shale is sandy, but in the stratigraphic horizons where coal is found clay shales are also found. The coal that occurs in these Tertiary rocks was studied years ago by Collier and was found from numerous analyses to be dominantly a high-grade lignite, with some subbituminous varieties. At the present time, with ample wood for domestic use and with cheap oil for large-scale mining operations, these low-grade coals are of little economic importance.

The base of an Upper Cretaceous-Tertiary conglomerate along the west bank of Mission Creek appears to lie directly upon pre-Upper Cretaceous granite, and in other areas arkosic sandstone can be observed to have been locally derived directly from granite, with which it is in contact. Besides granite, other constituents of the conglomerate include chert, schist, quartz, quartzite, and greenstone. Fragmental plant remains are interbedded with sandstones at various localities. Gold was found to be irregularly distributed in certain sandstone and conglomeratic beds and almost certainly were derived from weathering of the granitic rocks.

Igneous Rocks

Several Paleozoic and possible Precambrian igneous rock units have been mapped in the Eagle and Charley River quadrangles. A sequence of basalts and sedimentary rocks believed by Mertie to be Early Mississippian are known as the Circle Volcanics. Mesozoic granite, including some diorite and related rocks, form a large complex south of the Yukon River. Tertiary lava flows, mainly rhyolite but including some dacite, are present. This study is concerned principally with the Mesozoic granitic rocks which appear to have the greatest potential as uranium source rocks for the Upper Cretaceous-Tertiary trough sediments and as possible hosts for vein-type uranium.

The Mesozoic granitic rocks occupy a zone 80 miles long and from 10 to 50 miles wide with smaller outlying masses of similar rocks both north and south of the main massif. The total area is 1,900 square miles. The main body is named from the Charley River, which cuts the batholith about halfway between Eagle and Circle. Other batholiths and smaller granitic bodies occupy much of the Yukon-Tanana upland in east-central Alaska, as shown on the geologic map of the Eagle quadrangle (fig. 57).

The felsic rocks identified by Mertie (1930, p. 150) consist of muscovite granite, alaskite, muscovite-biotite granite, amphibolite, epidote granite, and quartz monzonite. Subsilicic types are granodiorite, quartz diorite, and diorite. Basic rocks include gabbro, peridotite, and pyroxenite. The granitic and dioritic rocks, however, are most typical of the region. Locally, primary granite gneiss is developed along the contact of the intrusives with the country rocks. Tertiary and Mesozoic dikes of both felsic and mafic compositions are common near the intrusive rocks. Ultramafic rocks of the Eagle quadrangle are described by Foster and Keith (1974).

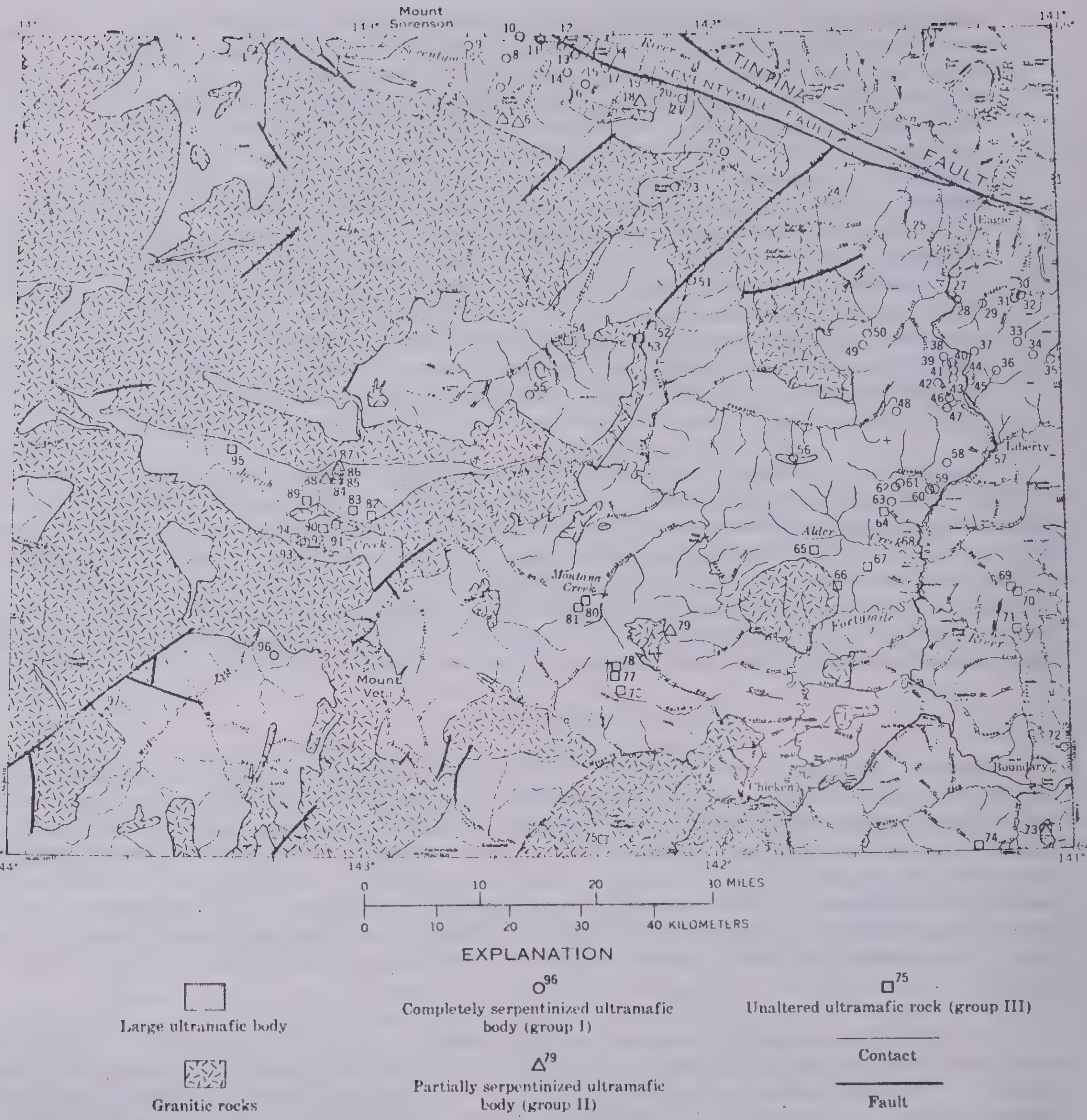


Figure 57. Igneous rocks of the Eagle quadrangle. (Source: Foster and Keith, 1974.)

The plutonic rocks of the main complex in the southwestern part of the Charley River quadrangle are termed adamellite (quartz monzonite) by Brabb and Churkin (1969). Their description follows:

> *Medium- to coarse-grained adamellite. Biotite is chief accessory mineral. Hornblende less abundant. Muscovite and garnet occur locally. Adamellite has zenoliths of schist and is cut by aplite dikes. The adamellite forms generally structureless bodies discordant with surrounding schist, but in some places the adamellite seems to grade into quartz biotite gneiss.*

The Mesozoic plutonic rocks in the Eagle quadrangle are described by Foster (1972):

> *UNDIFFERENTIATED GRANITIC ROCKS--Primarily quartz monzonite and granodiorite, but includes granite to diorite with local aplite, alaskite, and pegmatite. Fine to coarse grained; equigranular to coarsely porphyrytic. Biotite-hornblende granodiorite abundant. Commonly crops out in tors. Most of larger plutons probably Mesozoic in age but includes Tertiary plutons.*
>
> *HORNBLENDE GRANODIORITE--Primarily coarse-grained hornblende granodiorite and quartz monzonite but includes some gabbro and syenite. Probably Mesozoic in age.*
>
> *SYENITE OF MOUNT VETA--Primarily hornblende syenite porphyry, but locally equigranular. Includes hornblende quartz-monzonite and diorite. Potassium-argon age on hornblende of 177 m.y. ±5 m.y. (Potassium-argon report no. 54 (Menlo Park), 1969, by J. Von Essen).*

While both Mount Veta and Mount Fairplay are about 75 miles south of the Yukon River in the Yukon-Tanana Upland and outside the Eagle-Circle region, they are areas of syenite and are of interest because of the possibility of uranium associations (Foster, 1967). The Mount Fairplay area has long been known to have a very high radioactivity background, and even though it was the site of a uranium staking "rush" no commercial uranium deposits were found.

Another rock unit of possible interest because it may consist of Precambrian orthogneiss is the Pelly gneiss (Mertie, 1937, p. 201-202). This unit occurs in scattered, rather ill-defined areas throughout much of the Yukon-Tanana Upland of eastern Alaska. This unit is discussed in a section of this report devoted to the Pelly gneiss alone.

Structure

The most significant structural feature of the Eagle-Circle district is the Tintina Trench, extending 600 miles or more from Canada into east-central Alaska. Right-lateral displacement has been calculated to be as much as 260 miles. The trench forms a lowland now partly occupied by the Upper Cretaceous-Tertiary sediments of the Eagle-Circle district. Subordinate faults and folds related to movement in the fault zone are well developed in Precambrian-Paleozoic rocks and Cretaceous granite. Displacement of Quaternary alluvium shows that movement has continued (Davies, 1972).

The Tertiary rocks have been deformed into appressed folds. Bedding, though locally dipping northward, dips dominantly southward and it is presumed that the Tertiary rocks lie in a belt of appressed folds overturned to the north.

Economic Geology

Gold in placer workings have long been known in the region. All the streams mined for gold lie south of the Yukon River, as do the granitic intrusive bodies. The valleys of Coal and Woodchopper Creeks contained the most important placers in the Upper Cretaceous-Tertiary belt. While mining has been dormant for a number of years, a dredge on Coal Creek is currently being reactivated.

The Upper Cretaceous-Tertiary deposits have acted as a proximate source for the gold which in turn was concentrated in various tributaries of the Yukon River. The original source was the granitic plutons south of the Upper Cretaceous-Tertiary belt. All the important placers are on the valley floors, but less significant placers occur as bench deposits on higher and older erosional surfaces. Silver and platinum are alloyed with the placer gold; up to 18 percent silver and 0.42 percent platinum.

Lode deposits in the immediate vicinity of the Eagle Trough are scarce. Mineralization was staked in 1948 on sulfide-bearing rock containing cobalt bloom and a basaltic greenstone on Eagle Bluff just outside the town of Eagle along Mission Creek (Saunders, 1952). Very little work has been done on the prospects. A few lode prospects in the Circle district were explored for gold, copper, and lead. A copper prospect 50 miles east of Eagle on Copper Creek about 6 miles above its confluence with the Charley River occurs in highly metamorphosed rocks which may be a roof pendant in the Charley River batholith. Chalcopyrite, malachite, and azurite are the chief metallic minerals (White and Tolbert, 1954, p. 7-9).

Some low-grade coal has been exposed at several stream valleys cutting the Upper Cretaceous-Tertiary beds, but they apparently are not suitable for exploitation. One site which is believed to be in the Nation River Formation has been mined for coal, and about 2,000 tons were used to fuel river streamers (U.S. Geol. Survey 1964, p. 80). An occurrence of asbestos has been found near the center of the Eagle quadrangle in a serpentinized mass that appears to have intruded metamorphic rocks (Foster, 1969).

Radioactivity Investigations

Several reconnaissance investigations for radioactivity by the U.S. Geological Survey and one by the Alaska State Geological Survey have been conducted in west-central Alaska.

Wedow (1954) investigated the Eagle area in 1948 on behalf of the U.S. Atomic Energy Commission, and reported the following data:

> *Reconnaissance of radioactive deposits in sedimentary rocks of Proterozoic and Paleozoic age, and granite of Mesozoic(?) age together with its Tertiary sedimentary derivatives, was conducted in the Eagle-Nation area, east-central Alaska in 1948. None of the rocks examined contains more than 0.003 percent equivalent uranium except for black shale beds in the upper Mississippian Calico Bluff formation and in granite of Mesozoic(?) age and its sedimentary derivatives. The more radioactive black shale beds in the Calico Bluff formation range in thickness from 1/2 to 7 feet. Two units near the base of the formation appear to be persistent in the area: Radioactive unit A, with an average thickness of 6.6 feet, contains an average of 0.007 percent equivalent uranium and 0.004 percent uranium; radioactive unit B, with an average thickness of 5.2 feet, contains an average of 0.006 percent equivalent uranium and 0.003 percent uranium. Phosphatic pellets from unit B at one locality contain 0.022 percent equivalent uranium, 0.019 percent uranium,*

and 15 percent P_2O_5. Samples of granite of Mesozoic(?) age and its Tertiary sedimentary derivatives average 0.005 and 0.004 percent equivalent uranium, respectively. Biotite is the chief radioactive mineral in the granite and its radioactivity is ascribed to the presence of uranium and thorium, which occur either as impurities or in minute inclusions of other, as yet unidentified, minerals. Traces of uranium and thorium in zircon, sphene, and monazite also contribute to the total radioactivity of the granite. Zircon and monazite are the major uranium- and thorium-bearing minerals of the Tertiary sedimentary rocks derived from the granite.

Summary of pertinent data on the radioactivity of materials tested in the Eagle-Nation area, 1948

Age and type of material tested	Maximum radioactivity (percent eU)
Pre-Cambrian rocks:	
Limestone, dolomite, shale, and hematitic rocks of various types	0.001
Undifferentiated rocks of Paleozoic age:	
Argillite	.003
Cambrian system:	
Limestone	<.001
Carbonaceous shale	.003
Ordovician(?) system:	
Carbonaceous shale and quartzitic sandstone	.003
Silurian system:	
Limestone	<.001
Devonian system:	
Shale of various types, including carbonaceous beds, and volcanic rocks of greenstone habit	.003
Carboniferous systems:	
Lower(?) Mississippian rocks:	
Shale and chert	.002
Phosphatic(?) concretions	.003
Upper Mississippian Calico Bluff formation:	
Limestone	.007
Carbonaceous shale	.009
Phosphatic pellets in carbonaceous shale	.022
Intermediate or transitional formation:	
Shale and chert	.002
Pennsylvanian Nation River formation:	
Sandstone, conglomerate, and shale	.001
Carbonaceous shale	.003
Permian system:	
Tahkandit limestone	<.001
Triassic system:	
Carbonaceous shale and limestone	<.001
Mesozoic(?) era:	
Granite	.007
Tertiary system:	
Conglomerate, sandstone, and shale	.002
Coarse granitic detritus interbedded with minor amount of carbonaceous shale and fine-grained sandstone	.005
Quaternary system:	
Concentrates from present stream gravels	.003

The Copper Creek lode deposit prospect mentioned under "Economic Geology" was examined by Wedow and Tolbert (1954, p. 7-9). The prospect is on the right bank of Copper Creek about 6 miles above the confluence with the Charley River. A placer concentrate collected 100 feet upstream from the lode assayed 0.013 percent eU. Underground workings extend 114 feet, but ore showings occur only in the first 40 feet of the adit. Selected samples analyses are given in the following table:

Data on selected samples from the Copper Creek copper lode prospect, Eagle district

[Equivalent-uranium analyses by members of the Alaskan Trace Elements Unit]

Sample no.	Equivalent uranium (percent)			Remarks
	Unconcentrated rock	Fraction < 3.3 sp gr	Fraction >3.3 sp gr	
				Placer
3688	---------------	[1] 0.003	[2] 0.013	Concentrate from about 50 pounds of gravel in Copper Creek about 100 feet upstream from lode prospect.
				"Portal" anomaly
3730-L	0.032	[3] 0.044	[2] 0.003	Grab sample from most radioactive spot on east side of portal.
3731-L	.001	.003	.002	Grab sample from slightly radioactive part of ore zone on east side of portal.
				"40-44" anomaly
3725-L	0.003	0.010	0.002	Grab sample of rock adjacent to most radioactive iron-stained fracture zone.
3726-L	.006	.004	.003	Chip sample of 1-foot layer above most radioactive fracture.
3727-L	.003	[4] .012	.002	Chip sample of 1-foot layer below most radioactive fracture.
3728-L	.004	.006	.003	Grab sample of same fracture zone as sample 3725-L but about 6 feet downdip of fracture.
3729-L	---------------	---------------	---------------	Specimen of rock immediately below fracture in sample 3725-L; radioactivity appears to be confined to 0.1 foot of rock immediately adjacent to fracture.

[1]Fraction <2.8 sp gr.
[2]Fraction >2.8 sp gr.
[3]Contains 0.058 percent U as determined by F. S. Grimaldi, Washington Trace Elements Laboratory.
[4]Contains 0.009 percent U as determined by F. S. Grimaldi, Washington Trace Elements Laboratory.

The investigators concluded that the radioactivity at the Copper Creek prospect was due to uranium as impurities in bornite and malachite. They also noted that the investigations were limited and that greater concentrations may occur in the area of the mineralized roof pendant in the batholith.

Studies of placer concentrate samples from near Chicken in the Fortymile district of east-central Alaska revealed two placer concentrates containing significant amounts of radioactivity (White, 1954, p. 10-12). Both samples were from Atwater Bar on the South Fork of the Fortymile River, a short distance below the confluence of Mosquito and Dennison Forks. The eU of the samples were 0.041 and 0.033 percent. The radioactivity is due to traces of uranium-bearing thoianite, which occurs as minute black cubes and fragments. No data are available as to the source of the thorianite.

Another reconnaissance for uranium was conducted in the Fortymile district in the Wilson Creek, Ben Creek, and My Creek areas by Wedow and Tolbert (1949, p. 13):

> *A maximum of 0.005 percent equivalent was found in felsic igneous rocks of the Wilson Creek and Ben Creek areas. The radioactivity of these rocks in the Wilson Creek area is probably due to traces of radioactive elements in the common-accessory minerals of the igneous rocks; in the Ben Creek area it is probably due chiefly to thorium in monazite and allanite, which were identified in concentrates from gravels of streams draining areas underlain by the igneous rocks. Radioactivity tests of Tertiary sedimentary rocks in the vicinity of Chicken show that a sulfide-bearing montmorillonite-type clay contains as much as 0.005 percent equivalent uranium and that coked(?) coal and ash from a burned coal bed contain as much as 0.003 percent equivalent uranium. A concentrate submitted by a prospector from a gold-placer deposit at Atwater Bar, a short distance east of Chicken, contain traces of uranothorianite and has an equivalent uranium content of 0.027 percent.*

White and Tolbert (1954, p. 4-6) also examined granite in the Miller House-Circle Hot Springs area, about 40 miles west of Woodchopper Creek, and suggested that the granitic rocks in the area may warrant further investigation. A summary of their findings is quoted:

> *Granite of Mesozoic(?) age in the Miller House - Circle Hot Springs area, east-central Alaska, contains 0.005 to 0.007 percent equivalent uranium. The radioactivity is mostly caused by uranium in such primary accessory minerals of the granite as allanite, garnet, scheelite, sphene, and zircon. However, the presence of metallic sulfides, cassiterite, and uraniferous fluorite, malachite, and topaz in the granite or associated placers suggests the possibility of a post-emplacement or late-stage mineralization of the granite, presumably of hydrothermal origin, as a source for at least part of the uranium. Additional reconnaissance in the area to determine the presence or absence of hydrothermal uraniferous deposits of commercial grade appears warranted.*

Heavy mineral fractions of other samples from the Circle Hot Springs area yielded 0.06 percent eU from Hot Springs, Portage, and Ketchum Creeks, and as much as 0.012 percent eU from Nome Creek (Bates and Wedow, 1953, p. 10). Radiometric anomalies detected both from the air and on the ground were reported over granites in the Circle district (Matzko and Freeman, 1963, p. 40-41).

Granitic rocks along the Taylor Highway yielded anomalous eU values (White, Nelson, and Matzko, 1963, p. 79-80). A maximum of 0.015 percent eU was obtained from a granitic area just southwest of Mount Fairplay and from a weathered aplite dike north of Logging Cabin Creek. The radioactivity background was noted by the present writer to be about four times the average background for a distance of 15 miles along the Taylor Highway as it passes the Mount Fairplay area.

Results from other areas tested by the writer in west-central Alaska (Eakins, 1969, p. 13-14) are given below:

Tertiary shale, sandstone, and coal beds exposed along Chicken Creek at the town of Chicken and in a gravel pit near Chicken did not yield significant readings. The Silver Queen Lode, just below the highway about four miles north of Chicken and near Mile Post 71 did not show measureable radioactivity. The prospect consists of a 30-foot tunnel following a gouge zone with showings of galena.

Two feet of gouge in a fault zone in a conspicuous outcrop of marble in a road cut at Mile Post 114 gave three times the background count, or between 0.03 and 0.04 Mr/Hr. Tertiary sandstones and shales exposed in borrow pits along the Taylor Highway from a few miles south of Eagle to Eagle contain sandstone shales, and siltstones. The very fine-grained silty sandstones and siltstones were noticeably higher in radioactivity than the cleaner, coarser sandstones. Counts up to 0.03 Mr/Hr were obtained.

A foot traverse along American Creek from Eagle south for five miles was made to examine Tertiary sandstones and conglomerates exposed in bluffs along the creek. At three locations localized anomalies were encountered where faults cut these beds. The maximum readings were 0.03 Mr/Hr. Mission Creek enters the Yukon just west of the town of Eagle near the base of Eagle Bluff. The prominent Eagle Bluff stands between Mission Creek and the Yukon. In the 1940's several claims covering showings of gold, copper, nickel, and cobalt were staked along a fault zone on the Mission Creek side of Eagle Bluff. A foot traverse in this area did not produce any radioactive anomalies, but all seven claims were not examined in detail. No mining has been done on the claims.

Frequent checks with counters along the Yukon River between Eagle and the Canadian border revealed no anomalies in the Paleozoic rocks exposed. The Nation River conglomerate exposed no anomalous readings. The Mississippian Calico Bluff formation exposed on Calico Bluff about eight miles downriver from Eagle has been reported to contain radioactive black shales. The writer measured readings up to 0.05 Mr/Hr in black shales near the base of the bluff. A climb from the river to the top of the bluff produced lesser readings. Tertiary beds exposed on the south side of the Yukon from two to seven miles west of the mouth of the Seventymile River produced only very low radioactivity. A maximum reading of 0.05 Mr/Hr was obtained from one narrow brecciated zone cutting the beds.

Near the base of the Mississippian Calico Bluff formation on the Yukon River a few miles below Eagle, black shale beds contain between 0.005 and 0.01 percent eU. Pellets and nodules of phosphatic material scattered through some beds of these radioactive black shales contain up to 0.02 percent eU (Wedow, White, and Moxham, 1951, p. 106; Wedow, 1954, p. 3-4).

Discussion

The Upper Cretaceous-Tertiary nonmarine sediments in the Eagle Trough are essentially untested for uranium. The beds extend for 80 miles along the northern boundary of a region containing extensive granitic plutons which have displayed

radioactivity anomalies from the air and on the ground. For the most part the sandstones contain 0.002 percent eU. At least part of the Upper Cretaceous-Tertiary sequences has been shown to have been derived from the granitic bodies and to contain carbonaceous and coaly material. However, beds are generally folded and dips frequently are between 45° and 90°.

Many of the alkalic plutons in a broad region of the Yukon-Tanana Upland in east-central Alaska offer possibilities for nonsedimentary uranium deposits. Scattered small areas have been investigated and eU contents of up to 0.007 percent and averaging 0.005 percent have been found in the granite and related rocks. Stream concentrates and metallic prospects in the Fortymile and Circle Hot Springs districts are anomalous. Aerial radiometric survey and geochemical programs appear warranted to localize anomalies in both the Upper Cretaceous-Tertiary sandstones and the granitic rocks of the region.

KANDIK BASIN

The Kandik Basin lies principally in the eastern half of the Charley River quadrangle of east-central Alaska. It is a triangular-shaped area, bounded on the northwest by the Yukon Flats, on the east by the Canadian boundary, and on the south by the Eagle Trough along the Yukon River. This discussion, however, is restricted mostly to the central part of the Kandik Basin—Nation Arch area bounded by the Kandik River on the north, the Nation Arch on the Canadian border to the east, and the Yukon River on the south (fig. 58). The Eagle Trough has been discussed in the preceding section of this report.

The town of Eagle on the Yukon River near the southeastern edge of the area can be reached by the Taylor Highway. Parts of the Kandik Basin are accessible by boat by ascending the Kandik, Nation, and Tatonduk Rivers from the Yukon. Except for isolated settlements along the Yukon, the region is uninhabited.

The Kandik Basin, in contrast to most of the basins considered in this study, is not a topographic basin. It contains a thick sequence of sedimentary rocks that have been folded and uplifted to form the Ogilvie Mountains and Nation Arch. The geology and structure have been mapped on a scale of 1:250,000 by Brabb and Churkin (1969).

The Ogilvie Mountains rise to 5,000 feet in altitude, and the local relief is as much as 4,000 feet. It is a region of narrow valleys and gorges and precipitous slopes. Most of the region is underlain by permafrost. The mean annual precipitation is about 10 inches. Winters are long and very cold, but summers are generally warm and pleasant. The region is mostly heavily wooded; timberline is about 2,500 feet above sea level.

The Kandik Basin has attracted interest because of the high iron content of the Precambrian red beds, oil shale in the Triassic beds, and the possibility of petroleum in the Paleozoic and Mesozoic sections. This study will consider the possibility of uranium in sediments underlying the red beds and in continental sandstones in the Devonian and Cretaceous-Tertiary rocks.

Sedimentary Rocks

The Kandik Basin region is believed to present one of the most complete geologic sections in Alaska. Rocks representing Precambrian and all of the

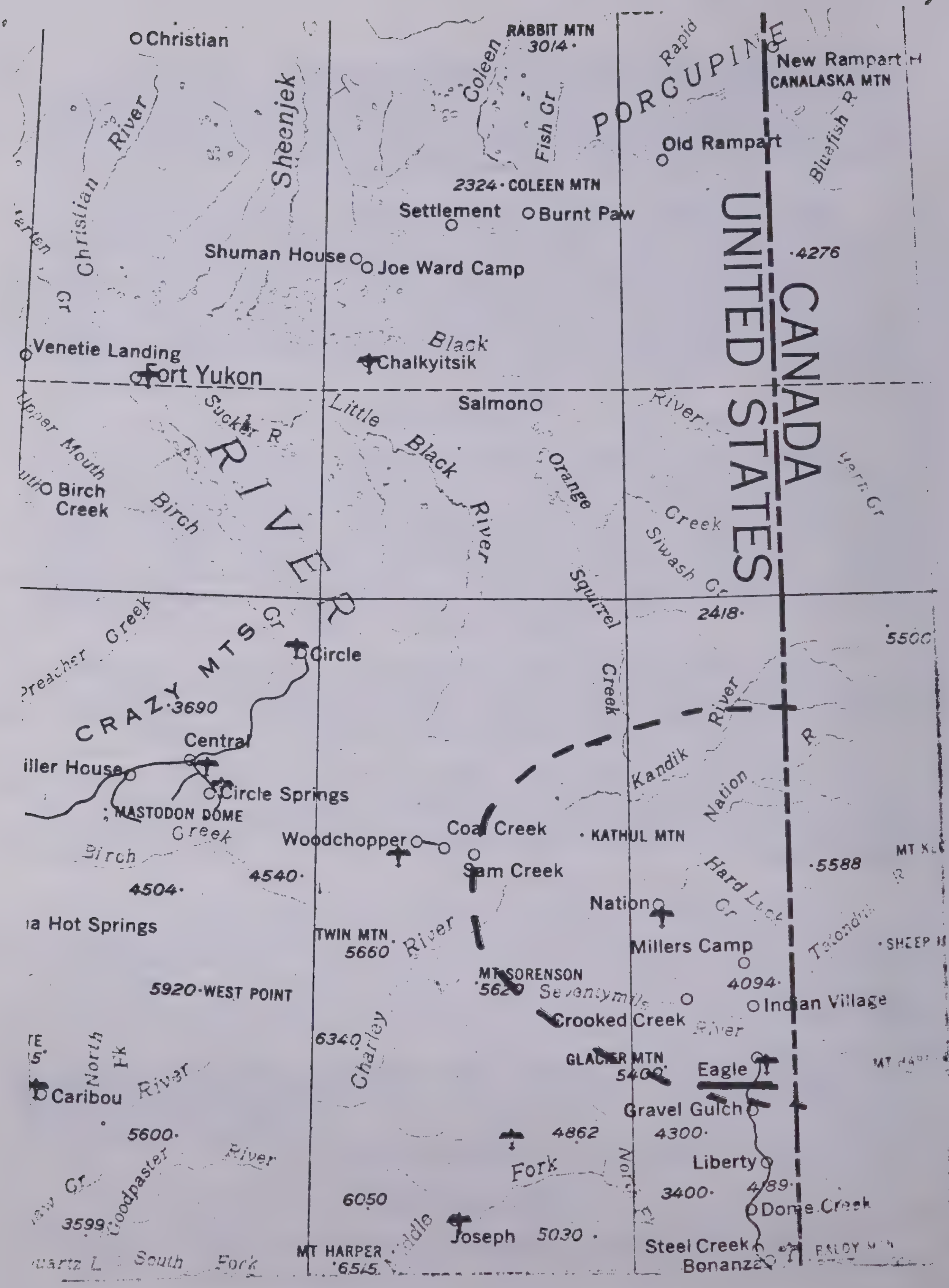


Figure 58. Index map of the Kandik Basin region.

Paleozoic and Mesozoic periods except the Jurassic and possibly the Pennsynvanian periods are present. Tertiary-Cretaceous nonmarine sediments occupy a large part of the north-central area. The geology is shown in figure 59. Descriptions of the formations in the Kandik Basin are reproduced below and accompany the geologic map compiled by Brabb and Churkin (1969).

One of the units of principal interest to a uranium potential study is the "Basalt and red beds" of the Tindir Group. The total thickness of the group, which includes a variety of sedimentary rocks and lava beds, is 20,000 feet or more. It underlies Middle Cambrian limestone and has been correlated with the Belt series of British Columbia. The red-bed unit is believed to be about 1,800 feet thick (Mertie, 1932, p. 380). The red beds are distributed over several areas within the Kandik Basin area, mostly north of the Yukon River, but one belt of red beds extends to the south across the river a few miles northwest of Nation. The rhythmically bedded siliceous iron-rich beds are probably correlative with similar beds of the Rapitan Formation in Yukon Territory.

The red color is due to iron content, which in places is as much as 26 percent of the rock. Cairnes (1914, p. 91-92) stated that the red-bed conglomerate is undoubtedly of terrestrial origin. Tuffaceous beds within the red-bed sequence are a hypothetical source of uranium. If a reducing environment below the red beds can be located, it would suggest an environment potentially favorable to a secondary uranium deposit.

A more detailed description of the red beds has been published by Mertie (1932, p. 375-377) as his unit C:

Section of beds of unit C

TOP OF SECTION

	Feet
Brownish-red argillite, with gritty phases. One of the gritty beds is composed of angular grains, half an inch or less in diameter, cemented by a red matrix. Under the microscope the component grains are seen to consist of angular fragments of dolomite and siliceous dolomite, agatelike mixtures of dolomite and quartz, small grains of quartz, pieces of slate, and irregular areas of chlorite or serpentine, cemented together by a hematitic argillaceous matrix.	*25*
Conglomerate composed of rounded to subangular pebbles, half an inch or less in diameter, in a reddish-brown matrix. Pebbles are principally dolomite	*7*
Red shale	*3*
Conglomerate	*1/2*
Red slate	*2/3*
Conglomerate. Subangular to angular pebbles from a fraction of an inch to 2 inches in diameter, with here and there a cobble as large as 12 inches. Rock fractures across the pebbles. Pebbles appear to be about 75 per cent dolomite and occur in shades from light gray to brown. Next to dolomite chert is the most noticeable material and occurs in various shades of blue, green, red, yellow, and gray. Also a minor	

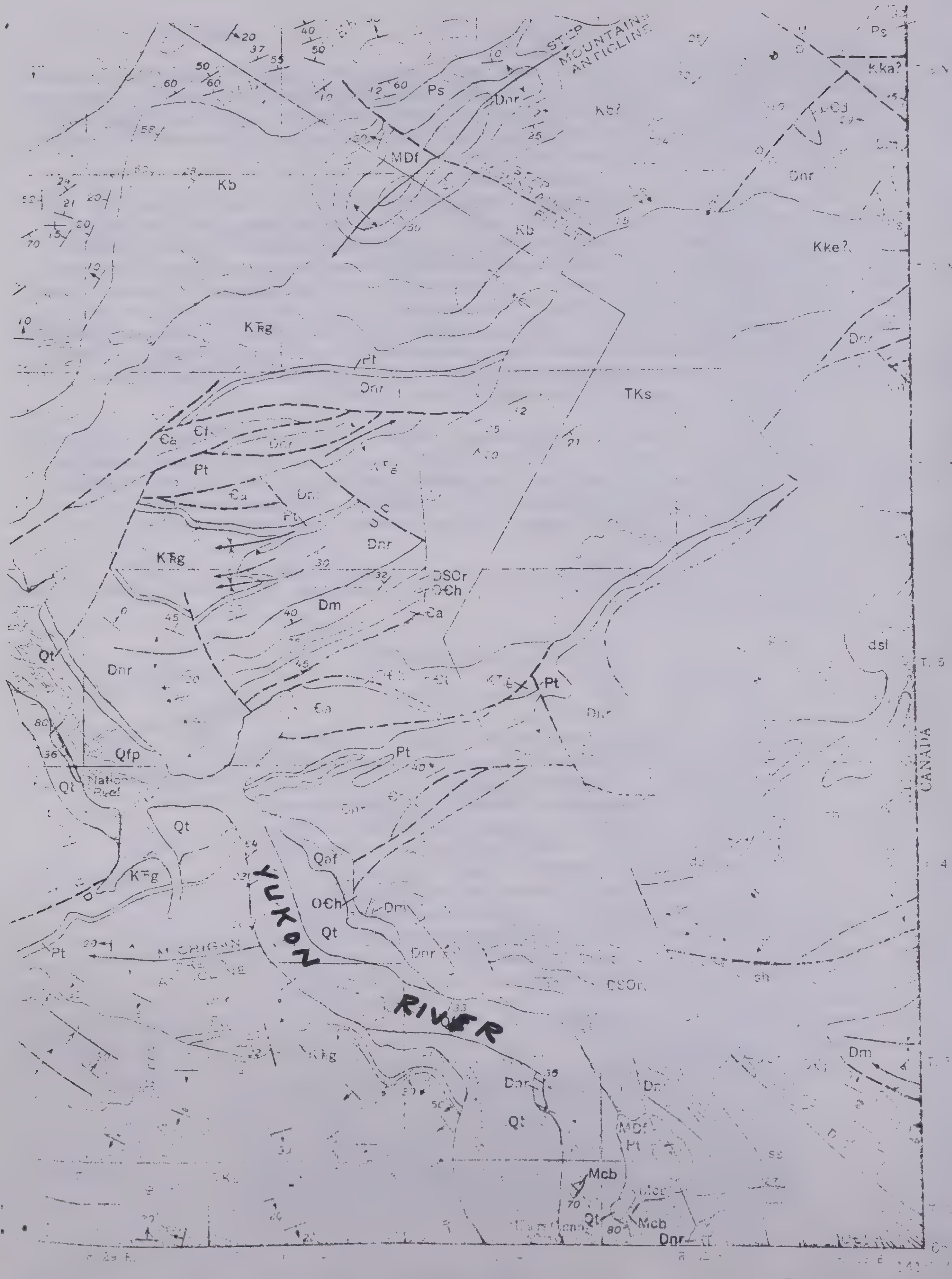


Figure 59. Geologic map of the Kandik Basin region. (Source: Brabb and Churkin, 1969.)

Upper Cretaceous to Pliocene (?)

TKs

Sandstone, mudstone, and conglomerate

Sandstone and conglomerate, poorly sorted, friable, composed mostly of lithic fragments and about 5 percent potash feldspar. Thin, lignitic coal beds common. Nonmarine. Thickness 200 to at least 3,000 feet

CRETACEOUS AND TERTIARY

UNCONFORMITY

NORTH OF TINTINA FAULT ZONE

STRATIGRAPHIC POSITION REASONABLY CERTAIN

Lower Cretaceous — Kandik Group — CRETACEOUS

Kka

Kathul Graywacke

Sandstone, conglomerate, and argillite. Sandstone, dark-greenish-gray, feldspathic (about 25 percent potash and plagioclase feldspar) graywacke with secondary chlorite and epidote. Conglomerate clasts of chert, volcanic rocks, argillite, and sandstone in matrix of graywacke or argillite. Argillaceous rocks mainly dark-gray argillite but include olive-gray shale and mudstone. Contains a few stratigraphically long-ranging marine pelecypods. Seems correlative with nonmarine rocks in Eagle quadrangle to the south which contain plants of probable Albian age. Thickness several thousand feet. Named and described by Brabb (1969)

LOCAL UNCONFORMITY

Kb

Biederman Argillite

Rhythmically interbedded, dark-gray argillite and medium-gray siltstone and sandstone. Siltstone and sandstone mainly quartz arenite commonly with carbonate cement. Convolute structures and cross-laminations common. Includes a few beds of chert-pebble conglomerate, siliceous shale, chert-limestone breccia and limestone. Contains very few pelecypods of Valanginian age near base. Thickness at least 5,000 feet. Named and described by Brabb (1969)

Kke

Keenan Quartzite

Medium-gray massive quartzite and sandstone with a few interbeds of dark-gray siltstone and argillite. Weathers white and forms resistant ridges. Locally contains abundant Buchia "sublaevis" *of Valanginian age. Thickness varies from 100 to 1,000 feet. Named and described by Brabb (1969)*

Middle Triassic to Lower Cretaceous — TRIASSIC TO CRETACEOUS

KTRg

Glenn Shale

Mainly grayish-black carbonaceous shale. Minor siltstone and quartzite. Phyllite and quartz-chlorite semischist in vicinity of Indian Grave Mountain are probably local metamorphic facies. Lower few hundred feet of Glenn Shale near Nation consist of dark-gray limestone and oil shale with Monotis, Halobia, Daonella, Discophyllites, *and* Nathorstites *of Middle Triassic (Ladinian) to Late Triassic (Norian) age. At other localities contains* Otapiria *of probable Jurassic age (Imlay, 1967, p. B7),* Buchia okensis *of Early Cretaceous (Berriasian) age, and* Buchia *cf.* B. crassicollis *of Early Cretaceous (probably Valanginian) age. Sparsely fossiliferous north of 65°25'N. Maximum thickness about 5,000 feet. Named and described by Brabb (1969)*

UNCONFORMITY(?)

Pt

Tahkandit Limestone

Very pale orange, coarse-grained bioclastic limestone. Forms massive cliffs. Grayish-green glauconitic sandstone and chert-pebble conglomerate in basal 75 feet. Contains abundant brachiopods and a few corals, arenaceous foraminifers and bryozoa. Maximum thickness about 350 feet

Ps

Step Conglomerate

Chert-pebble conglomerate and chert arenite. Minor siltstone, bioclastic limestone, and quartz arenite. Has Tahkandit fauna in Step Mountains area. Nonfossiliferous and of uncertain age in western and northern part of quadrangle except for single Permian fauna from sandstone near Takoma Bluff. Thickness about 2,000 feet. Named and described by Brabb (1969)

PERMIAN

UNCONFORMITY

MISSISSIPPIAN

Upper Mississippian

Mcb

Calico Bluff Formation

Rhythmically interbedded, dark-brownish-gray and brownish-black limestone and shale. Maximum thickness approximately 1,000 feet

Upper Devonian to Upper Mississippian

MDf

Ford Lake Shale

Grayish-black laminated siliceous shale and chert. Minor dark-gray siltstone, quartzite and limestone. Plant stems common. Thickness about 1,000 feet. Named and described by Brabb (1969)

DEVONIAN

Upper Devonian

Dnr

Nation River Formation

Rhythmically interbedded, mudstone, sandstone, gritstone, and conglomerate. Graded beds common. Mudstone is olive gray and nearly everywhere contains plant fragments and spores of Late Devonian age. Sandstone is olive-gray chert-quartz arenite and wacke, commonly with carbonate cement. Gritstone and conglomerate composed mostly of varicolored chert granules and pebbles. Thickness approximately 2,000 to 4,000 feet. See reports by Brabb and Churkin (1967) and Scott and Doher (1967)

Lower, Middle(?), and Upper Devonian

Dm

McCann Hill Chert

Thin-bedded and laminated dark- to light-gray chert, siliceous shale, and minor chert gritstone. Contains plant fragments, poorly preserved spores, and rare conodonts, gastropods, and cephalopods. Basal part of formation has beds of dark-gray bioclastic limestone with remarkably varied fauna including corals, brachiopods, trilobites, tentaculitids, fish, and ostracods of Early Devonian (Emsian) age. Thickness 200 to 800 feet except near Jones Ridge where it may be a few thousand feet thick. Named and described by Churkin and Brabb (1965a). Additional faunas listed by Churkin and Brabb (1968)

Dl

Limestone

Medium-gray limestone and calcareous shale. Contains a few brachiopods, corals, and bryozoa of Devonian age. Thickness a few hundred feet

SILURIAN AND DEVONIAN

ORDOVICIAN

CAMBRIAN

Lower Ordovician to Lower Devonian

DSOr

Road River Formation

Dark-gray graptolitic shale with lesser amounts of grayish-black laminated chert and very minor dark-gray limestone, greenish-gray dolomite, chert arenite, and conglomerate. Chert, chert arenite, and chert conglomerate occur mainly in basal part of formation. Graptolites indicate that most series of the Ordovician and Silurian are represented, and that the youngest rocks are Early Devonian (pre-Emsian). Thickness 400 to 900 feet. See reports by Churkin (1966) and Churkin and Brabb (1965a, 1967)

DISCONFORMITY

Lower Cambrian to Lower Ordovician

O€h

Hillard Limestone

Very fine to medium-grained pale-yellowish-brown limestone. Laminated to very thick bedded, shaly to massive parting. Has interbeds of edgewise limestone conglomerate, oolitic limestone, and sandy limestone. Minor dolomite, grayish-black chert, dark-gray fissile shale and siltstone, and a basal limestone boulder conglomerate. Fossils, especially trilobites and brachiopods, are common. Age, Early, Middle, and Late Cambrian and (near Tatonduk River) earliest Ordovician. Thickness 100 to 500 feet. See reports by Brabb (1967) and Palmer (1968)

Lower Cambrian

€a

Adams Argillite

Light-olive-gray argillite, siltstone, and cross-laminated quartzite. Worm(?) burrows occur in quartzite; Oldhamia (see Churkin and Brabb, 1965b) in argillite. Oolitic and sandy limestone near base has archaeocyathids, and trilobites of Early Cambrian age (Palmer, 1968). Thickness 300 to 600 feet. Named and described by Brabb (1967)

€f

Funnel Creek Limestone

Light-gray fine- to medium-grained laminated limestone and dolomite. Extensively silicified and commonly oolitic. Forms massive cliffs. Non-fossiliferous. Thickness 50 to approximately 1,300 feet. Named and described by Brabb (1967)

O€j

Jones Ridge Limestone

Lower 2,000 feet of lower member is mainly very light gray, massive limestone and dolomite. Extensively silicified and commonly oolitic, pisolitic, and laminated. Upper 940 feet of lower member is pale-yellowish-brown, very fine grained, thin- to thick-bedded limestone. Upper member 60 feet thick is pale-yellowish-brown thick-bedded bioclastic limestone.

Lower member has archaeocyathids of Early Cambrian age and trilobites and other fossils of Late Cambrian and Early Ordovician age. Upper member has rich fauna of Middle or Late Ordovician age. Age of Jones Ridge is therefore considered to be Early Cambrian to Middle or Late Ordovician. Total thickness about 3,000 feet. Named and described by Brabb (1967). Fossils described by Palmer (1968) and Ross and Dutro (1966)

Upper Precambrian

Tindir Group

ss

Limestone

Dark-gray and brownish-black laminated limestone with platy and slabby parting. Has interbeds of greenish-gray shale, siltstone, and sandstone, and minor pale-yellowish-brown sandy and gritty limestone, light-gray dolomite, and chert-carbonate gritstone. Thickness approximately 500 to 1,500 feet. Unit A of Mertie (1933, p. 370)

UNCONFORMITY(?)

ss

Dolomitic sandstone and shale

Mainly light-gray thin- to medium-bedded sandstone (doloarenite) and olive-gray shale. Minor gritstone and conglomerate. Doloarenite composed mostly of rounded dolomite grains with subordinate chert and quartz grains. Cross-laminations common. Weathers very pale orange and resembles crystalline dolomite at a distance. Gritstone and conglomerate composed mostly of dolomite and chert clasts and some granules, pebbles, and cobbles of granitic, volcanic, and metamorphic rocks. Maximum thickness about 2,400 feet. Unit B of Mertie (1933, p. 372)

Basalt and red beds

Dark-greenish-gray basalt, commonly amygdaloidal and with pillow structures. Feldspar and pyroxene mainly unaltered but at a few localities they are chloritized, and the rock is a greenstone. Minor basaltic tuff with pebbles and cobbles of basalt. Red beds mostly grayish-red shale and siliceous shale. Minor greenish-gray shale and siliceous shale, jasper, greenstone-dolomite conglomerate, hematitic doloarenite, and vitric tuff and lava largely replaced by hematite and carbonate. Thickness 300 to at least 2,500 feet. Units C, D, and part of G of Mertie (1933)

ds dsl

Dolomite and shale

Light- to medium-gray laminated dolomite and grayish-black shale. Minor chert, doloarenite, and dolomite-chert gritstone. The dolomite weathers very pale orange and is cut by diabase dikes. Thickness about 3,000 feet. Part of units E, F, and G of Mertie (1933)

dsl; *medium-gray stromatolite-bearing limestone with slabby and massive parting. Seems to be a lentil within the dolomite and shale unit. Thickness approximately 100 to 500 feet. Part of Unit F of Mertie (1933)*

sh

Shale

Grayish-black carbonaceous shale with minor interbeds of quartzite, dark-gray limestone, oolitic limestone, laminated dolomite, massive dolomite, and dolomite conglomerate. Cut by diabase dikes. Shale is a few thousand feet thick. Part of units E, F, and G of Mertie (1933)

Tindir Group, undivided

Mainly dolomite and shale

PRECAMBRIAN

	Feet
proportion of greenstone pebbles. Matrix appears to be mainly siliceous	*15*
Red shale with some jasper	*41*
Dolomite	*3*
Conglomerate, same as that described in detail	*30*
In part covered but believed to be mainly a soft red shale	*77*
Several varieties of brownish-red rocks, including shale, slate, argillite, and jasperoid material. One specimen of the red argillite is seen under the microscope to be composed mainly of angular grains of dolomite and less quartz, cemented by hematitic argillaceous material. This specimen also shows solution cavities filled by dolomite and replacements of the same material along lines of banding. Another specimen (30AMt115), which was analyzed, seemed to be almost massive hematite, with solution cavities now occupied by dolomite and quartz. The beds range from 1 inch to 1 foot in thickness; the thicker ones usually conglomeratic. Some beds of red shale, particularly in the lower part of this sequence, contain scattered boulders of dolomite as large as 2 feet in diameter, some of which are well rounded and others quite angular	*36*
Red beds of different types, including dolomitic, argillaceous and cherty varieties, and also altered lavas. Specimens 30AMt124 and 30AMt125, which were found on microscopic examination to be lavas replaced by hematite, were analyzed. Specimen 30AMt124, which may originally have been an andesite, is a hyalocrystalline rock composed of plagioclase laths in rock glass. The rock is exceedingly fine grained, the feldspars not exceeding 0.2 millimeter in length. The rock glass is now much altered to hematite, and the feldspars are altered to carbonates. Specimen 30AMt125 originally was probably a basalt but is somewhat coarser grained, and its feldspars are completely altered to calcite. It also contains a few grains of angular quartz and some nearly colorless chlorite. This rock may possibly be tuffaceous. One of the sedimentary specimens in this zone was seen under the microscope to consist of angular grains of dolomite, more or less silicified, and a few pieces of hematitic slate, cemented by an opaque hematitic matrix	*393*
Discontinuous exposures of red beds of same general character	*447*
Red beds, consisting of argillaceous, dolomitic, quartzitic, and cherty types	*223*
Conglomerate	*1*

	Feet
Red siliceous rock. Specimen analyzed (30AMt127). Found by microscopic examination to be fragmental and probably tuffaceous. Consists of angular to subangular as well as rounded grains of glassy igneous rock, probably originally black but now altered almost completely to hematite. The interstitial material is largely dolomite, with some grains of detrital quartz and some almost isotropic pale-green chlorite. The basaltic glass contains here and there laths of calcified plagioclase but more commonly irregular-shaped grains of chloritic and opaloid material	16
Mottled red and green conglomerate and grit. The gritty material is seen under the microscope to be probably tuffaceous, consisting of subangular to angular grains of several kinds of lavas, both andesitic and basaltic, cemented by a hematitic matrix. The mafic minerals are entirely chloritized, but the lath-shaped feldspars are little altered. The old amygdaloidal cavities, filled with calcite and chlorite, are well preserved. The hematitic matrix is filled with small, irregular-shaped grains of chlorite, calcite, and quartz, part of which probably represent original detrital grains. The matrix varies of opacity according to the amount of alteration to hematite	2
Red beds exposed to south side of the Tatonduk River and not examined at close range	240
Red beds. In the lower part of this sequence the beds are folded, and thickness was estimated	300
Basal red conglomerate. This member of the formation does not crop out on the Tatonduk River but appears on tributaries both to the north and south. On the south tributary this red basal conglomerate lies in a fault zone, and it is doubtful if more than 200 feet of it is exposed. On Funnel Creek, the north tributary, it crops out for about a mile but is so massive that the structure is hard to determine. At this locality the conglomerate was observed by Cairnes, and Cairnes's estimate of 800 feet for its thickness is here used, although the true thickness may be only half that amount.	800±

The Devonian Nation River Formation of the Kandik Basin area is of interest as a possible host rock for uranium. The Nation River is a nonmarine sedimentary unit up to 4,000 feet thick exposed on both sides of the Yukon River in the southeastern part of the Charley River quadrangle. This formation is also discussed in the section on the Eagle Trough. The sandstone beds that contain carbonaceous material seem to warrant examination. The age and correlation of this unit have been studied by Brabb and Churkin (1967, p. D4-D15; and by Laudon and others, 1966, p. 1868-1889). Mertie (1930, p. 113-121) described the Nation River but

considered it to be Carbonaceous in age rather than Devonian. The rocks of the Nation River Formation area include 2,000 to 4,000 feet of shale, sandstone, conglomerate, and a little bituminous coal. Mertie stated that the sandstone contained chert, decomposed feldspar, quartz, and carbonaceous material. The structure of the beds is not particularly complex.

Nonmarine Upper Cretaceous-Pliocene sediments lie in an irregular 150-square-mile area north of the Yukon River near the Canadian border. The sediments contain poorly sorted, friable sandstone and conglomerate and thin lignitic coal beds which overlie the Lower Cretaceous Kandik Group. The thickness is from 200 to at least 3,000 feet (Brabb and Churkin, 1969). The Upper Cretaceous-Pliocene beds are probably the same formation as the Cretaceous-Tertiary beds in the Eagle Trough south of the Yukon River, but they have been described in this area only in a very general way. Mertie (1930, p. 142) supplied the following information on the rocks along the Yukon River:

> *Where seen along the Yukon, the Upper Cretaceous and Eocene rocks consist of impure greenish-gray to almost black sandstone, graywacke sandy shale, and beds ranging from grit to coarse conglomerate. A short distance above the international boundary, in the hills north of the Yukon, the conglomerate consists of pebbles from a quarter of an inch to 3 inches in diameter, in a brownish matrix. The pebbles here were mainly of vein quartz and chert, with some quartzite, quartzite schist, graphitic phyllite, and decomposed granitic or dioritic material. This is about the average character of the conglomerate. At some places, however, the conglomerate is coarser, and boulders as large as 3 feet in diameter have been observed. At most localities all these rocks are loosely consolidated and therefore by weathering form on top of the ridges gravel deposits that stimulate high bench gravel. At places, however, as for example in the valley of the Seventymile River, these rocks have been more than ordinarily metamorphosed and occur as hard, well-indurated sandstone and conglomerate.*
>
> *A small area of coarse conglomerate and sandstone is shown at the head of the Charley River. These rocks consist of gray more or less carbonaceous sandstone, interbedded with very coarse conglomerate containing boulders as much as 6 feet in diameter. Like most of the strata of this series, they carry plant remains.*

Igneous Rocks

The only igneous rocks that have been mapped within the subject area are lavas in the Precambrian Tindir Group. Churkin (1973, p. 6) made the following statement:

> *The base of the Tindir is not known, but rare boulders of granitic rock and gneiss in the upper part of the Tindir suggest that an igneous and metamorphic rock basement of earlier Precambrian age is not far away.*

The possibility of Precambrian rocks being in the region is attractive because their presence would increase the chances for uranium occurrences either as veins within the basement rocks or as weathered products in younger sediments.

A large Paleozoic granitic body lies across the Alaska-Yukon border 6 to 23 miles north of the Porcupine River in the northeastern part of the Coleen quadrangle. This pluton is north of the Kandik Basin, but it may be favorable for uranium and is mentioned here because of the relative close proximity to the Kandik district.

The pluton is described by Brosge and Reiser (1969) as biotite granite and quartz monzonite with minor muscovite locally; partly porphyritic. Rhyolite and aplite dikes appear on the borders of the granite. The K-Ar age of the muscovite is 295-335 m.y. (Mississippian). The pluton on the Alaskan side of the border occupies about 400 square miles.

Most of the granitic rocks in the interior of Alaska are Mesozoic or Tertiary in age, and it may be that older plutons are more favorable for uranium than the younger ones. The age and composition of the granitic rocks north of the Porcupine River indicate that they should be investigated for radioactivity. A little reconnaissance sampling of these rocks for radioactive minerals was done in the headwaters of Sunaghun Creek along the southern edge of the pluton and close to the Canadian border (White, 1952). The results indicated that the granite might be somewhat anomalous in radioactive material (0.006 percent equivalent uranium).

Structure

The major structural features of the Kandik area are the Nation Arch (the axis of which trends east-west and crosses the national boundary a few miles north of Eagle) and the Tintina Trench (Eagle Trough) along the south side of the Yukon River. Folds several miles long on the flanks of the Kandik Arch are evident on the geologic map. Two sets of faults are prominent: a northwest-trending set, and an east-west-trending set. A discussion of the structure of the area is taken from Miller, Payne, and Gryc (1959, p. 63-64):

> *The structure of the Kandik province appears to be simpler than that of the area to the south, along and south of the Yukon River. The dominant strike of the beds is northeast and almost at right angles to that in the area to the south, which approximately parallels the course of the Yukon River. A major fault zone follows the course of the Yukon and extends southeastward into Canada. Because the strong deformation of the rocks south of the river has involved rocks at least as young as the middle part of the Cretaceous, it is believed that this area may have been affected by an orogeny, probably early Tertiary in age, that had relatively little effect on the Kandik area. Such a condition might explain the less intense deformation and the different strike of the rocks to the north, which may have been affected primarily by the Early Cretaceous orogeny.*
>
> *The major structures of the privince are broad, open folds, on which minor folding and crumpling, particularly in shale beds, are superimposed. Dips measured by Cairnes and Mertie range in general from 10 degrees to 60 degrees and commonly are 30 degrees to 40 degrees. Locally steeper dips were recorded and were believed to be in the vicinity of faults.*

Economic Geology

The Kandik Basin has attracted attention because of the iron in the Tindir red beds, oil in Triassic oil shales, phosphate in Cambrian and Triassic beds, and the possibility of petroleum in the Paleozoic and Mesozoic sediments. No lode deposits or placers have been reported.

Broad folds and the thick stratigraphic section, which includes oil shale in the Triassic and bituminous limestone and shale in the Cambrian and Mississippian sequences, suggest the possibility of petroleum reservoirs, but no drilling has been done (Brabb, 1965, p. 1757-1758; Miller, Payne, and Gryc, 1959, p. 62-64).

The Upper Triassic oil shale from the Trout Creek area has yielded 28 gallons of crude oil per ton (Mertie, 1937, p. 262-264). Triassic oil shale also occurs at the mouth of the Nation River. The oil shales have not been evaluated.

Phosphate deposits occur in limestone of Cambrian age in the Tatonduk River area between the Canadian boundary and the Yukon River and in Triassic rocks near the confluence of the Nation River and the Yukon River. No information on the deposits was located.

The U.S. Bureau of Mines (Kimball, 1969) reported on the Precambrian hematitic red beds along the Tatonduk River, 17 miles northeast of Eagle. Nearly 800 feet of stratigraphic section was chip sampled. Soluble iron content varied from 4.75 percent from a 3-foot thickness to 24.7 percent for a 9-foot thickness.

Radioactivity Investigations

Five samples of the Tindir Group red beds were tested for radioactivity by the U.S. Bureau of Mines (Kimball, 1969, p. 9). No radioactivity was detected.

A statement regarding radioactivity investigations of the red beds by the U.S. Geological Survey (Wedow, 1954, p. 2) is quoted:

> *The pre-Cambrian rocks of the Eagle-Nation area are strata of the Tindir group (Mertie, 1933, p. 369-392). They are exposed along the Tatonduk River and along the southwest bank of the Yukon River below Nation (pl. 1). Mertie divides the group into seven units, of which only three were accessible enough to be investigated during this reconnaissance. These three units, from youngest to oldest, are as follows (Mertie, 1933, p. 370):*
>
> *"Unit A. Principally thin-bedded limestone.*
> *Unit B. Principally siliceous dolomite and shale, with beds of dolomitic conglomerate near base.*
> *Unit C. Upper red beds, consisting of hematitic dolomite, shale, flint, tuff, and lava, with a red basal conglomerate."*
>
> *The three units have an aggregate stratigraphic thickness of about 6,500 feet.*
>
> *The red beds of Unit C were of particular interest in this reconnaissance in that they are similar, both lithologically and in age, to sedimentary rocks of Proterozoic age in the vicinity*

of Great Slave Lake, Northwest Territories, Canada (Stockwell, 1936), from which samples of reddish carbonate rocks containing 0.17 percent thorium oxide and 0.006 percent uranium had been obtained by the Geological Survey. According to Lang (1952, p. 63, 65), ferruginous dolomite around McLean Bay on Stark Lake, near Great Slave Lake, contains monazite and pitchblende on uraninite as original constituents of the rock. Radioactivity traverses of the pre-Cambrian strata in the Eagle-Nation area in 1948, both on the Tatonduk River and along the Yukon River below Nation (pl. 1), revealed no radioactive material that contains more than 0.001 percent equivalent uranium.

The U.S. Geological Survey made a reconnaissance for radioactivity north of the Kandik Basin along the upper Porcupine and lower Coleen Rivers. A summary of the investigation follows (White, 1952, p. 1):

> *The highest equivalent uranium content found in the sedimentary rocks on the upper Porcupine River, northeastern Alaska, is 0.005 percent. Rhyolitic dikes associated with a granitic intrusive a few miles north of the Porcupine, along the international boundary, contain about 0.006 percent equivalent uranium, which is attributed to small amounts of disseminated radioactive accessory minerals. The granite is also slightly radioactive.*

Sediments of Precambrian, Paleozoic, and Mesozoic ages were tested. Very little is known about the rocks in that area, and additional study is needed, especially of the granitic rocks, to determine their uranium potential. Regarding the above investigation, Wedow (1959, p. 41-42) had this to say:

> *The major sedimentary rock types of interest in the area were radioactive black shales of Paleozoic age similar to formations in the United States that contain large reserves of lowgrade uraniferous material; and Precambrian red beds, which at one locality in northwestern Canada contain deposits with monazite and pitchblende or uraninite (Rabbitt, 1947; Lang, 1952, p. 63, 65). On the other hand none of the Precambrian strata traversed contained radioactive materials similar to those found in beds of comparable age in Canada. Granitic rocks of Mesozoic age in the lower Mission Creek area near Eagle contain minor amounts of the radioelements in such accessory minerals as biotite, zircon, and monazite, whereas in similar rocks along the international boundary north of the Porcupine River the radioactivity is due to trace amounts of unidentified uranium minerals.*

The 1973 Annual Report of Inexco Oil Company, page 8, indicated "Kandik Basin uranium exploration under way." This writer has not learned if the exploration was actually conducted or not.

Discussion

Possibilities for uranium deposits in the Kandik Basin region appear to exist in the following rocks:

(1) Sediments below the Precambrian Tindir Group red beds wherever a reducing environment might be found.
(2) In the Nation River nonmarine carbonaceous sandstones.
(3) In nonmarine Cretaceous-Pliocene sandstones.
(4) In the biotite granite and quartz monzonite pluton north of the Porcupine River.

The general distribution of these rocks are shown on the maps by Brabb and Churkin (1969) and Brosge and Reiser (1969).

Cambrian limestones and shales with bituminous contents and Triassic oil shales may serve as reductants for any uranium entering these rocks in solution. The possibility of nearby Precambrian igneous or metamorphic basement rocks in the Kandik Basin, as suggested by Churkin (1973, p. 6), is of interest.

Granitic rocks north of the Porcupine River may deserve evaluation for uranium. Their Paleozoic age and composition seem favorable. Crushed samples of granite and rhyolite from the locality produced eU values of 0.006 percent.

TERTIARY COAL-BEARING BASINS, NORTH FLANK OF THE ALASKA RANGE

Nonmarine coal-bearing sediments occur intermittently in a 250-mile-long belt on the north flank of the Alaska Range from a point 25 miles east of Farewell eastward to 20 miles east of Donnelly on the Richardson Highway (See Geologic Map of Alaska: Dutro and Payne; 1957). These sediments lie mostly in the northern foothills of the Alaska Range physiographic division of Wahrhaftig (1965, p. 35-36; pl. 1). The foothills consist of flat-topped, east-trending ridges 2,000 to 4,500 feet in altitude which form a belt up to 20 miles wide along the Nenana River. Most of the foothills are unglaciated, but some valleys were widened during the Pleistocene Epoch by glaciers from the Alaska Range. Streams draining the north slope of the Alaska Range flow northward through the foot hills to the Tanana River valley, except in the western part of the belt, where drainage is into the headwaters of the Kuskokwim River. The Alaska Range forms a great arc extending 600 miles from the Canadian border to Lake Clark in southwestern Alaska, where it merges with the Aleutian Range. The crest of most of the range is between 7,000 and 9,000 feet in altitude, but mountain masses are higher.

Most of the Tertiary basins in the foothills are relatively accessible; none are too remote from towns, and the terrain is not extremely rugged. The belt is crossed by two north-south highways and a railroad: the Richardson Highway crosses the belt near the eastern end, and the Anchorage-Fairbanks Highway and the Alaska Railroad cross the Alaska Range through the Nenana River Valley at the eastern edge of Mount McKinley Park. Precipitation is less than 20 inches a year. Permafrost is extensive. The foothills belt is covered by the Big Delta, Fairbanks, Kantishna River, Mount Hayes, Healy, and Mount McKinley 1:250,000 topographic maps. Geologic maps of eight 15-minute quadrangles were recently issued and provide detailed information on much of the Healy and Fairbanks quadrangles (Wahrhaftig, 1970a-h). The surficial geology of the central part of the Alaska Range and Nenana River valley is covered by Wahrhaftig (1958).

The best known part of the Tertiary coal-bearing belt is along Healy Creek, where Usibelli Coal Mines, Inc. produces coal near the settlements of Healy and Suntrana (fig. 60). The coal is used to fuel two power plants, which serve Fairbanks and the military bases in the region. Healy Creek is part of the Nenana coal field, which includes several separate but closely grouped basins in a 40-mile-long area, mostly between the Nenana and Wood Rivers. This group of basins includes Healy Creek, Lignite Creek, Rex Creek, Tatlanika Creek, Mystic Creek, and Wood River Coal Basins (fig. 61). The Nenana coal field has been described by Martin (1919), Barnes and others (1951), and Wahrhaftig and others (1969).

Another locality where coal has been mined from the Tertiary beds on the north flank of the Alaska Range is the Jarvis Coal Field, located 100 miles east of Healy on the east side of the Richardson Highway near Donnelly.

Little detailed information is available on other Tertiary basins in the belt, but it is hoped that the following discussion, which mostly describes the rocks in the Nenana coal field on the north flank of the central part of the Alaska Range, will apply somewhat to all the Tertiary coal basins in the belt.

Sedimentary Rocks

Rocks in the valley of Healy and Lignite Creeks include the Precambrian (or Paleozoic) Birch Creek Schist, the Tertiary coal-bearing group, and the Tertiary Nenana gravels. For lack of a more up-to-date stratigraphic table, the one below is reproduced from Barnes and others (1951) with the understanding that the Birch Creek Schist may be wholly or in part Paleozoic in age and that the coal-bearing group has been revised upward from a formation to group status and formally divided into five new formations (table 7) (Wahrhaftig and others, 1969).

A discussion of the many Paleozoic and Mesozoic formations and intrusive rocks composing the Alaska Range is beyond the scope of this study, which is concerned mostly with the Tertiary coal-bearing group. The underlying Birch Creek Schist, however, is prominent in the Tertiary basins and deserves mention. It consists of highly contorted quartz-mica and quartz-chlorite schist with some interbedded phyllite, argillite, and black carbonaceous schist. These are all cut by numerous veins of milky quartz. When fresh, the schist is green. It weathers to shades of gray, green, and black, and becomes fissile.

Another unit that is exposed in the hills north of Healy is the Totatlanika Schist of pre-Devonian age. It consists of gray to black quartz muscovite and graphitic schist with interbedded argillite and metamorphosed volcanic rocks.

The Tertiary coal-bearing sequence lies unconformably on the Birch Creek Schist in the Nenana coal field. The coal-bearing rocks are well exposed in the Healy Creek valley and in the open-pit coal mines operated by Usibelli. Figures 62 and 63 show the structure of the coal-bearing beds in the Healy Creek valley and the relation to adjacent formations. Figure 64 shows the structure of Lignite Creek. The geology has been mapped on the Healy D-7 quadrangle (Wahrhaftig, 1970c).

The coal-bearing group (is up to 2,000 feet thick but) shows a wide variation in thickness and lithology within short distances. Apparently it was deposited in valleys or depressions in the Birch Creek Schist. Later deformation tilted the beds and in places formed synclines. It is unconformably overlain by up to 4,000 feet of the Tertiary Nenana gravel. South of the Healy Creek valley the beds are fairly flat-lying for a distance of several miles.

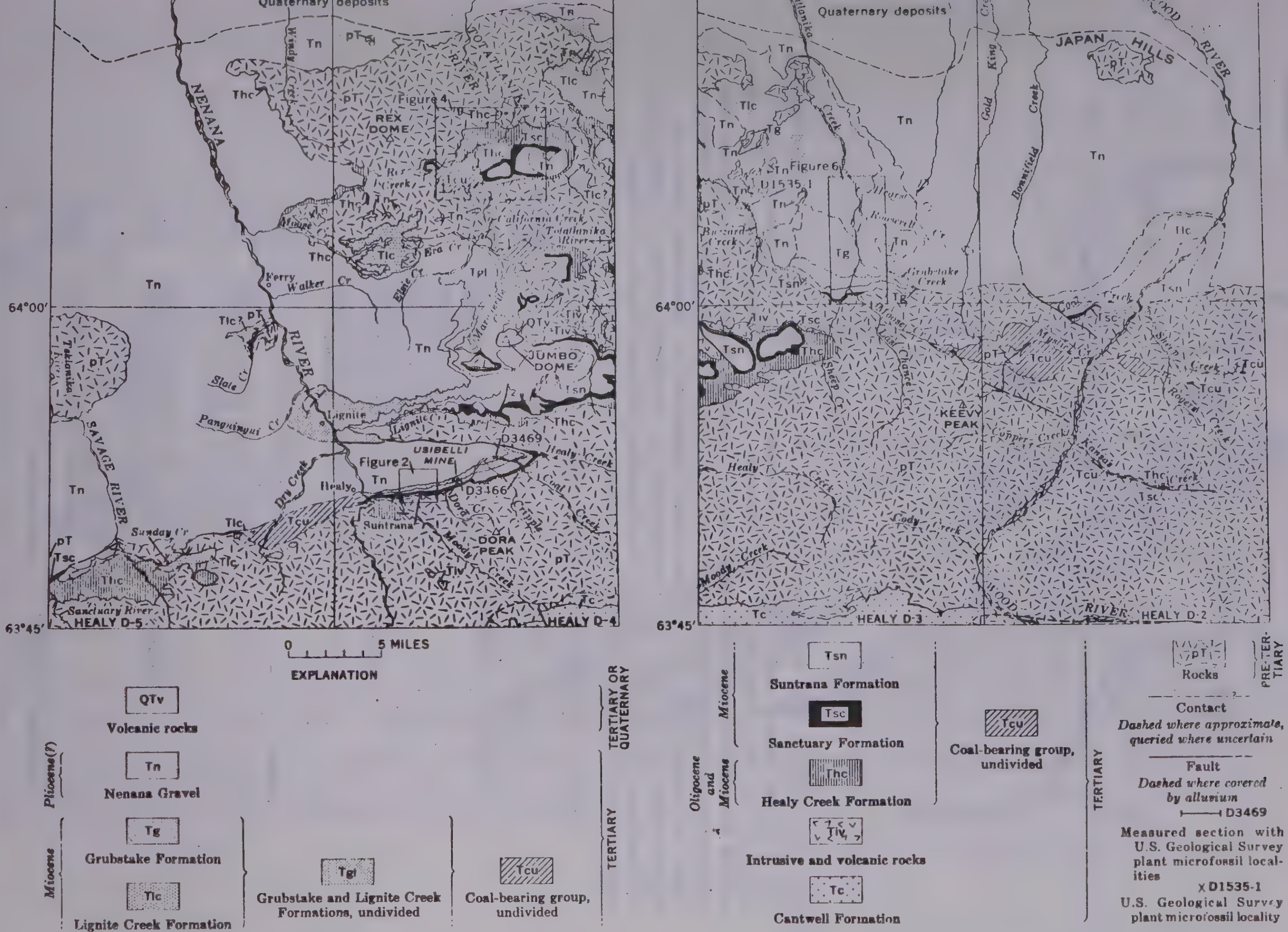


Figure 60. Generalized geologic map of the Healy D-2, D-3, D-4, and D-5 quadrangles and the Fairbanks A-2, A-3, A-4, and A-5 quadrangles, showing distribution of Tertiary formations and localities mentioned in text. (Source: Wahrhaftig and others, 1969, fig. 1.)

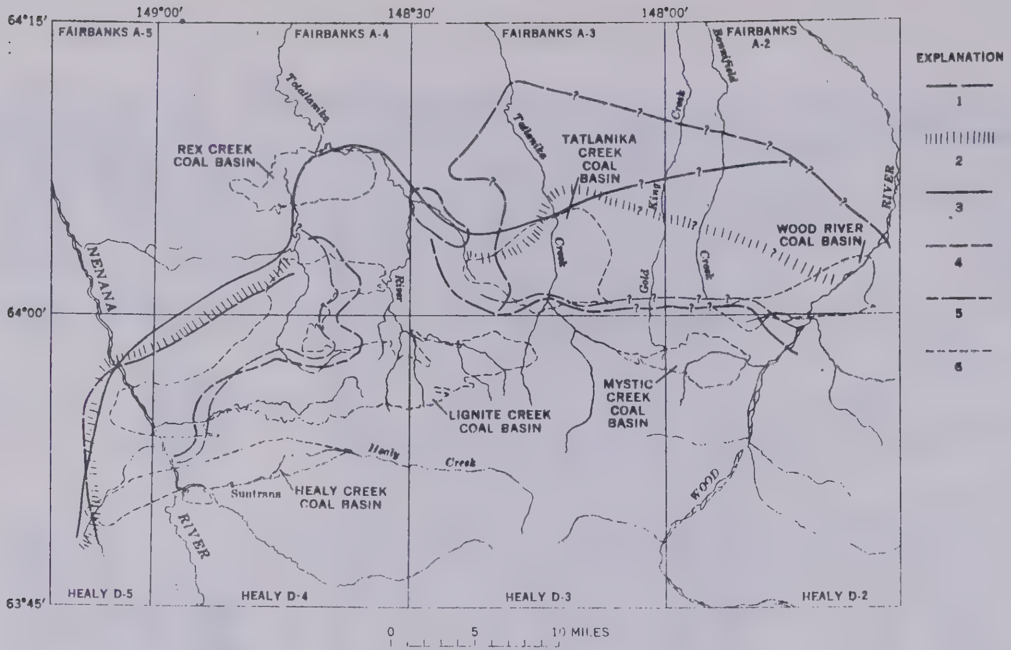


Figure 61. Map of the Nenana coal field and environs, Central Alaska Range, showing the major coal basins of the coal field and northern limits of several of the formations. 1. Northern limit of deposition of the Grubstake Formation; 2. Approximate zone of interfingering of coal-bearing and noncoal-bearing facies of the Lignite Creek Formation; 3. Northern limit of deposition of the Suntrana Formation; 4. Northern limit of deposition of the Sanctuary Formation; 5. Northern limit of deposition of the Healy Creek Formation; 6. Boundary of coal basin. (Source: Wahrhaftig and others, 1969, fig. 5.)

Table 7. Generalized stratigraphy of Nenana coal field.

Age	Formation	Description	Thickness (feet)
Quaternary	Terrace gravels Unconformity		0–200
Tertiary	Nenana gravel	Conglomerate, with boulders of Birch Creek schist.	200+
		Conglomerate, reddish-brown, with boulders of green ophitic diorite, granite, graywacke, and older conglomerate, and thin shale beds.	2,100
		Conglomerate, brown, with boulders of graywacke, conglomerate, green ophitic diorite, granite, graywacke, and conglomerate.	
		Conglomerate, brown, with boulders of graywacke, conglomerate, green ophitic diorite, and dacite.	1,000
		Conglomerate, brown, with boulders of graywacke, conglomerate, and dacite.	900
	Coal-bearing formation	Upper member: Sandstone, siltstone, claystone, and shale, with a few thin coal beds. Characterized by abundance of granite, volcanics, green ophitic diorite in pebble zones.	500–945
		Middle member: Sandstone, siltstone, claystone, numerous thick coal beds. Characterized by abundance of quartz, quartzite, chert, and argillite, and scarcity of granite, volcanics, and green ophitic diorite in pebble zones.	450–1,000
	Unconformity	Lower member: Sandstone, claystone, siltstone, and conglomerate, with numerous thick coal beds. Persistent brown-weathering claystone at top.	50–1,500
Pre-Cambrian	Birch Creek schist	Quartz-mica schist.	?

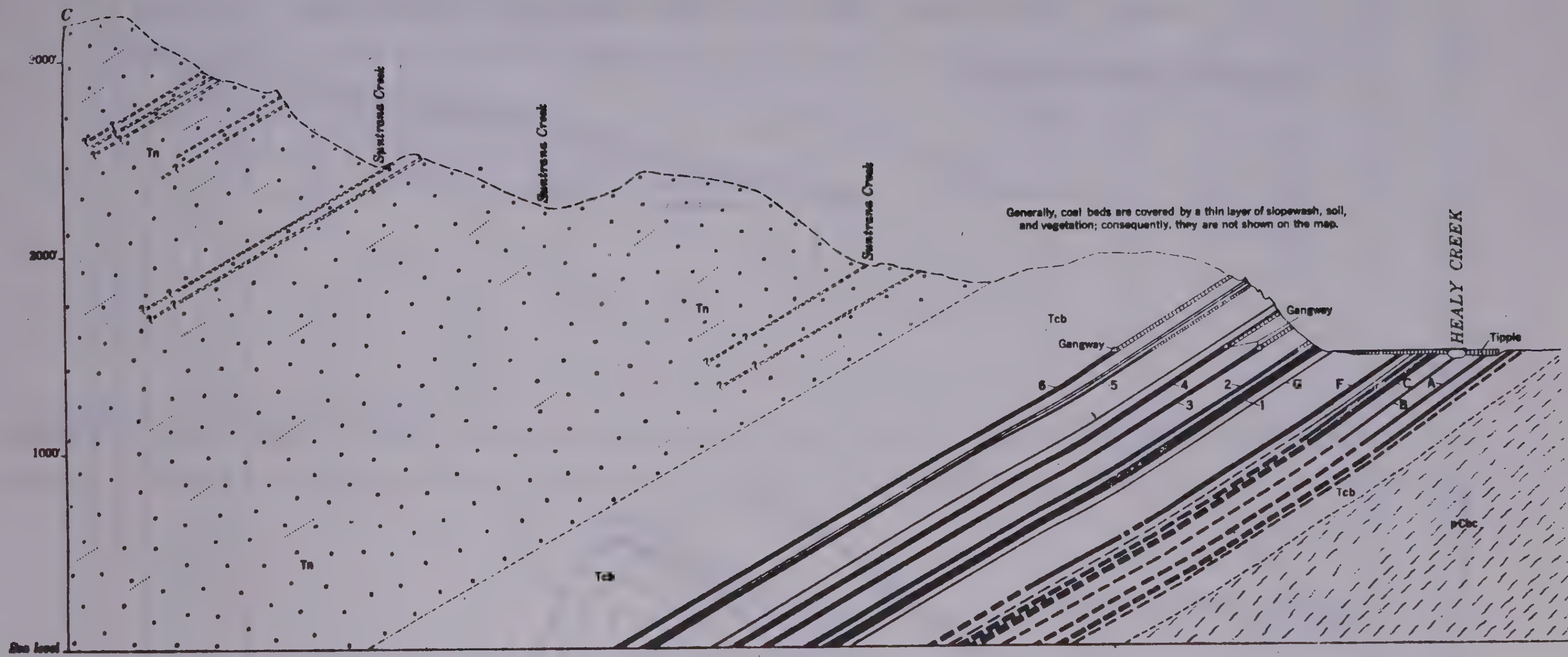


Figure 62. Cross section of the lower Healy Creek valley, looking east. (Source: Barnes and others, 1951, pl. 18; 1-1/4 inch = 1000 feet.)

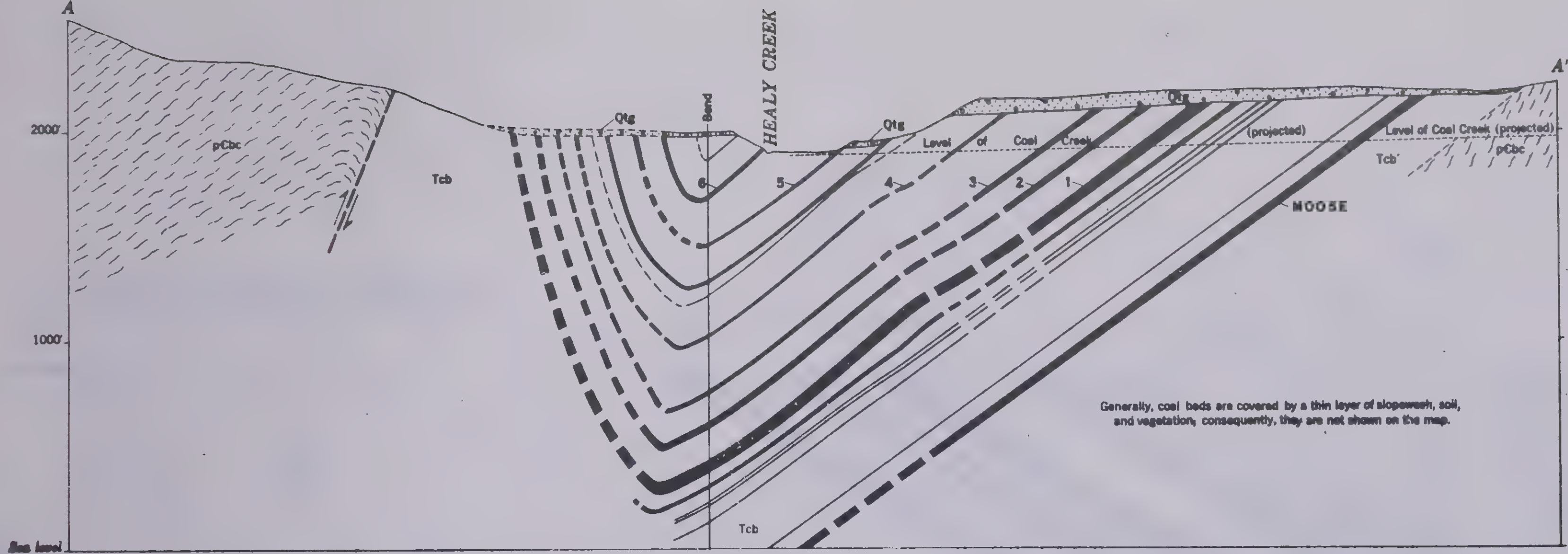


Figure 63. Cross section of the upper Healy Creek valley, looking east. (Source: Barnes and others, 1951, pl. 18; 1-1/4 inch = 1000 feet.)

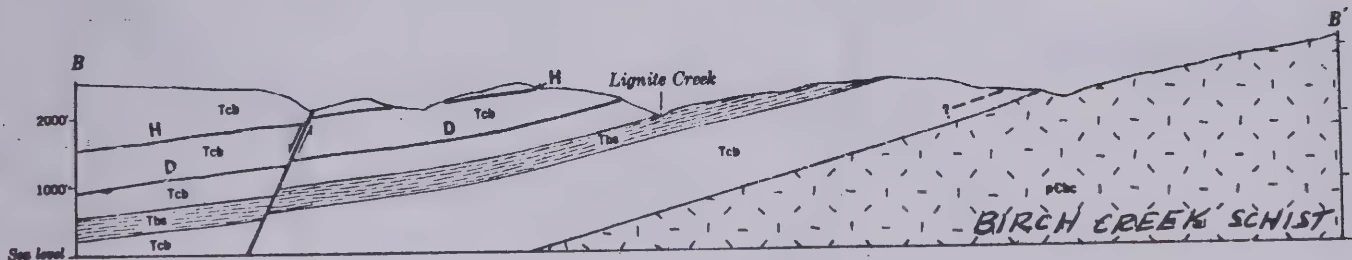


Figure 64. Cross section of the Lignite Creek coal basin, looking east. (Source: Wahrhaftig, 1945, pl. 20; 2 inches = 1 mile.)

Descriptions of the five new formations composing the coal-bearing group as defined by Wahrhaftig and others (1969, p. D7-D27) are summarized below.

Healy Creek Formation. The Healy Creek Formation of Oligocene and Miocene age is probably the most widely distributed member of the coal-bearing group, but its distribution is patchy. Its type section is on the northeast wall of the canyon of Healy Creek at Suntrana, where it rests unconformably on the Birch Creek Schist. The maximum measured thickness is 1,150 feet. About 2,000 feet of the Jarvis coal field sediments have been correlated with the Healy Creek Formation. The lithology of this formation in the Healy Creek area is taken from Wahrhaftig (1969, p. D8-D9):

> *As the lower member of the coal-bearing formation, it was recognized from the Sushana River on the west (Wahrhaftig, 1951, p. 174-175) to the Jarvis Creek coal field on the east (Wahrhaftig and Hickcox, 1955, p. 359), a distance of 125 miles. Many if not most of the isolated patches of coal-bearing rocks, which are a few hundred yards to a mile or two across and are widely scattered throughout the Alaska Range and adjacent regions, should probably be correlated with the Healy Creek Formation.*
>
> *The Healy Creek Formation was deposited on an irregular surface of considerable relief; in places this surface stood above the level of the base of the overlying formations, and in these places the Healy Creek Formation was never deposited. Because of this irregular basal surface, the thickness of the Healy Creek Formation varies markedly over short distances.*
>
> *The maximum measured thickness in the Nenana coal field is 1,150 feet on the south side of the Lignite Creek coal basin near the western edge of Healy D-3 quadrangle. It is 800 feet thick at the east end of the Healy Creek coal basin and about 1,000 feet thick in the Mystic Creek coal basin. About 2,000 feet of beds in the Jarvis Creek coal field have been correlated on the basis of lithology with the Healy Creek Formation (Wahrhaftig and Hickcox, 1955, p. 357-359).*
>
> *The Healy Creek Formation consists of interbedded poorly consolidated sandstone, conglomerate, claystone, and subbituminous coal. The most characteristic features of this formation are the lenticularity of its beds and the tendency for its lithologic components--pebbles, sand, clay, and coal--to be mixed together in the same bed rather than to be cleanly separated as they are in the overlying formations. Thus, many of the coals are thin bedded, lenticular, and bony, and thin claystone partings thicken abruptly and grade into coarse sandstone; sandstones, commonly have a clay binder; and claystones with pebbles and angular rock fragments are common, especially near the base of the formation.*

Sanctuary Formation. The Sanctuary Formation is a brown-weathering shale 90 to 130 feet thick at its type section near Suntrana, but it reaches 350 feet at the east end of the Healy Creek coal basin. It is the top part of the lower member in the stratigraphic table shown above. Its age is early or middle Miocene or both. Over most of its area, the Sanctuary Formation rests conformably on the Healy Creek Formation, but overlaps it in places and rests on the Birch Creek Schist. Wahrhaftig and others (1969, p. D13-D15 gave this description:

The Sanctuary Formation is predominantly a gray shale that weathers to a characteristic chocolate brown or yellowish brown. In clean exposures, such as the narrow gully floors that score its outcrop at Suntrana, the shale is seen to be finely banded (possibly varved) with alternating pale-weathering and dark-weathering laminae a fraction of an inch to an inch thick. Exposures that exhibit bedding are rare, for the shale breaks down quickly on exposure to a mass of flat yellow-brown chips that have split along the bedding, and where it is continually saturated with water, it forms masses of brown to gray sticky mud and is the locus of persistent large landslides. Its yellow-brown color on weathered outcrops and the tendency to break into flat yellow-brown chips that make the Sanctuary Formation a useful stratigraphic marker in the Nenana coal field.

Suntrana Formation. The Suntrana Formation, of middle Miocene age, is the "middle member" shown in the preceding stratigraphic table. It contains the bulk of the coal reserves in the Nenana coal field and is widely exposed in the Healy Creek and Lignite Creek coal basins, and may be present in the Rex Creek coal basin. Wahrhaftig and others (1969, p. D16-D17) described the lithology:

The Suntrana Formation is a many-times-repeated sequence with coarse pebbly sandstone grading upward from the base through medium- and fine-grained sandstone to clay and coal at the top. Generally there is only one thick coal bed at the top of each unit, but in some places two or three thin coal beds are interbedded with the claystone. In a typical sequence the sandstone at the base is 20-100 feet thick, the clay and silt unit is 2-15 feet thick, and the coal is 2-40 feet thick. On the average there are eight repetitions of this sequence in the formation, but in the northern part of the Lignite Creek coal basin there are as few as five or six, and in the sections at the head of Lignite Creek and at the east end of the Healy Creek coal basin there are as many as 10 or 12. The formation as a whole averages about 70 percent sandstone (including pebble beds) and 15 percent each coal and clay.

The sandstone is poorly consolidated, generally clean, well sorted, and crossbedded. It is chalk white to very light buff, although it may be stained by iron oxide to orange or red for a foot or two above each coal bed. In the field this type of sandstone was called salt-and-pepper sandstone because under a hand lens it is seen to consist predominantly of white grains with a scattering of black- to dark-gray grains of chert. This salt-and-pepper appearance is quite different from that of the more colorful sandstone of the overlying Lignite Creek Formation. Petrographic studies by M.C. Blake (written commun., 1959) showed that quartz makes up 70-75 percent of the sandstone; othoclase, 5-10 percent; plagioclase, 1-5 percent; chert and rock fragments, 5-10 percent; and heavy minerals, chiefly of low-grade metamorphic suites, 6-1/2 percent.

The pebbles, which average 1/4 to 1 inch in diameter, consist of more than 65 percent quartz, chert, quartzite, argillite,

and jasper--resistant rock types--and of less than 35 percent nonresistant rocks such as granitic rocks, gabbro, greenstone, graywacke, or volcanic rocks. Below the No. 5 coal bed the proportion of resistant rock types in the pebble population is about 80 percent.

The coal beds, which are generally 10-60 feet thick, can be traced laterally for long distances and appear to thicken regularly to a single maximum for each bed, located either in the eastern part of the Healy Creek coal basin or in the southern part of the Lignite Creek coal basin. The coal is black with a dark-brown streak, is comparatively low in ash, and characteristically breaks into small equidimensional blocks.

The Suntrana Formation appears to have accumulated in a subsiding basin whose axis lay at the south edge or to the south of the present coal field. Current directions indicated by the persistent crossbedding of the sandstone are predominantly southward in the Healy Creek and Lignite Creek coal basins and are westward in the Tatlanika Creek and Wood River coal basins. The source area of the clastic components probably lay in the southern Yukon-Tanana Upland, including the area of the Livengood Chert (Mertie, 1937, p. 105-111).

Lignite Creek Formation. The type section for the Lignite Creek Formation is on Suntrana Creek. It makes up the lower five-sixths of the upper member of the coal-bearing formation in the preceding stratigraphic table. It is probably mid-Miocene in age. The following description is from Wahrhaftig and others (1969, p. D19-D21):

The Lignite Creek Formation has two facies: a coal-bearing facies, exposed in Healy Creek and Lignite Creek coal basins and in the southern part of the Tatlanika Creek and Wood River coal basins; and a noncoal-bearing facies in the northern and western parts of the coal field. The noncoal-bearing facies was mapped by Capps (1940, pl. 3) as the Nenana Gravel.

The coal-bearing facies is about 500 feet thick in the northwestern part of the Lignite Creek coal basin and thickens southeastward to about 750 feet thick at the east end of the Healy Creek coal basin. It is about 620 feet thick in the Tatlanika Creek coal basin and about 800 feet thick in the Wood River coal basin. Like the Suntrana Formation, it is made up of a repeated sequence of pebbly sandstone, claystone, and coal. In contrast to the Suntrana Formation, the top of each sequence in the Lignite Creek Formation has several thin coal beds interbedded with claystone. Five sequences are present at the type locality. The coal-bearing facies averages about 5 percent coal, 30 percent siltstone and claystone (with interbedded fine-grained sandstone), and 65 percent sandstone, pebble beds, and conglomerate.

Sandstone units in the coal-bearing facies are as much as 160 feet thick. Some are laterally persistent, but others grade laterally into claystone or lens out altogether. The sandstone is generally poorly consolidated, clean, crossbedded, well sorted, and permeable. It is buff and under the hand lens is seen to contain an abundance of variously colored grains. This

contrast with the salt-and-pepper sandstone of the Suntrana Formation is one of the most readily recognizable distinctions between the two formations. Petrographic study by M.C. Blake (written commun., 1959) showed the sandstone to consist of 65-70 percent quartz, 10-15 percent plagioclase, 5-10 percent orthoclase, 10 percent chert and rock fragments, and 10 percent heavy minerals. Etched pigeonite grains, an abundance of fresh ferromagnesian minerals and predominance of plagioclase over orthoclase distinguish the sandstone of the Lignite Creek Formation petrographically from that of the Suntrana Formation.

Pebble layers and conglomerate beds make up 20-50 percent of the lower parts of some of the sandstone units, and conglomerate beds are as much as 20 feet thick. Average pebble size is 1-2 inches and the maximum size at a given locality is 6-8 inches. Rocks that are relatively unresistant to weathering--such as granite, diorite, gabbro, greenstone, basalt, andesite, rhyolite, schist, conglomerate, and graywacke--make up 35-60 percent of the pebble population, including most of the cobbles and boulders; resistant rock types--quartz, chert, quartzite, argillite, and jasper--make up the remainder. Individual counts of 75-150 pebbles were repeated many times in each measured section, and the abrupt change in pebble population at the top of the No. 6 bed was the principal means for distinguishing the Lignite Creek from the Suntrana Formation.

Crossbedding in the sandstone of the Lignite Creek Formation indicates current directions to the west and southwest in the noncoal-bearing facies and in the coal-bearing facies of the Tatlanika Creek coal basin. Elsewhere current directions are persistently to the south. A northward increase in grain size and pinching out of coal and clay indicate a source of clastic components to the north.

Grubstake Formation. The Grubstake Formation is the uppermost formation of the coal-bearing group and is given an provisional age of late Miocene. It is between 600 and 1,000 feet thick at its type section on Tatlanika Creek, and apparently rests conformably on the Lignite Creek Formation. The Grubstake Formation is overlain by the generally flat-lying Nenana gravel. Of special interest to the exploration for uranium are the presence of two thick volcanic ash beds in the Grubstake.

A discussion of the Grubstake Formation is from Wahrhaftig (1969, p. D22-D26):

The Grubstake Formation appears to underlie three separate areas in the Nenana coal field. The largest and thickest body extends from the western part of the Tatlanika Creek coal basin to the Wood River and appears to underlie much of the plateau of Nenana Gravel around Bonnifield and Gold King Creeks. Maximum thicknesses of this body are about 1,500 feet north of Coal Creek and 1,000 feet in the basin of Grubstake Creek, and the formation appears to thicken abruptly (in places by as much as 500 feet per mile) from its line of pinchout. The second body lies on lower

Buzzard Creek in the southwest part of Fairbanks A-3 quadrangle and reaches the Lignite Creek and Healy Creek coal basins; it thickens southward from a line of pinchout where the Lignite Creek-Nenana Gravel contact crosses Elsie Creek in southwestern Fairbanks A-4 quadrangle to about 250 feet at the east end of the Healy Creek coal basin.

In the Buzzard Creek and Tatlanika Creek-Wood River bodies, the claystone of the Grubstake Formation is dark gray, poorly consolidated, silty, and massive. Locally, it is thin bedded or varved and greenish gray. It contains numerous coaly partings and thin beds of coal and bone. The coal is usually about an inch thick; the thickest bed is 1 foot. Interbedded with this claystone are beds of dark-gray, poorly consolidated sandstone 3-40 feet thick, with abundant grains of black chert, dark rock fragments, and dark minerals. This sandstone weathers brownish red and is stained orange on joints and cracks. Conglomerate layers with pebbles 1/4 to 1/2 inch in diameter (maximum 1-1/2 inches) are also present. Pebbles are milky quartz and dull-black chert, both apparently reworked from the conglomerate of the Cantwell Formation 17-35 miles to the south.

Two thick beds of fine white vitric ash are exposed in the lower part of the Grubstake Formation at USGS paleobotany locality 9930 on the east bank of Tatlanika Creek between the mouths of Roosevelt and Hearst Creeks. The lower ash is about 24 feet thick in the exposure, with small-scale crossbedding, and the upper ash is about 13 feet thick. White outcrops seen in the bluffs from a helicopter for about 2 miles south of the fossil locality are thought to be of the ash. No white outcrops were spotted in a helicopter traverse of Grubstake Creek, nor was any ash seen in a ground traverse of the large gully exposure in the Grubstake Formation at the head of Coal Creek, but the base of the formation is not exposed in the gully.

The ash consists of more than 99 percent glass in lune-like shards and contains less than 1 percent crystals of chlorite, muscovite, quartz, plagioclase, and sanidine. Eruption of the lower ash apparently buried a forest growing at the site, and erect coalified trunks, rooted in place, rise 15-20 feet into ash. USGS paleobotany locality 9930 is the buried litter of this forest.

It was not possible to obtain pure separates of the minerals because of their rarity and small size. The biotite separate (-150+200 mesh fraction) contains about 90 percent biotite and 10 percent chlorite. The muscovite separate (-150+270 mesh fraction) only contains about 50 percent muscovite; plagioclase, quartz, sanidine, and glass make up the remaining 50 percent. Potassium-argon analyses of the biotite and muscovite concentrates gave ages of 57.3 and 54.4 million years, respectively. A determination on the glass itself gave an age of 8.1 million years. This should be regarded as a minimum age for the ash. A discussion of the implications of these dates follows the fossil data.

The Grubstake Formation in the Healy Creek and Lignite Creek coal basins is greenish-gray thin-bedded shale and claystone. At its base is a thin bony coal bed. The upper part of the shale has several sand and silt beds and commonly grades into dark sandstone at the top. At about one-fourth to one-third of its thickness above the base is a zone of thin chalky weathering layers with closely spaced lines of parting perpendicular to the bedding. Microscopic examination of these layers showed they contained abundant glass shards with the same refractive index as the ash on Tatlanika Creek. The presence of this ash in both areas establishes the correlation of the shale on Healy and Lignite Creeks with the type Grubstake Formation.

A study of clay mineralogy has been determined to be useful tool for stratigraphic correlations within the coal-bearing group (Triplehorn, 1974). Some montmorillonite beds are thought to be derived through the alteration of glassy volcanic material.

Overlying the coal-bearing group with angular unconformity is the Pliocene(?) Nenana Gravel, which is at least 4,000 feet thick in the Healy Creek area. The lower part consists of 700-1,500 feet of predominantly coarse sandstone with interbedded conglomerates. Pebbles of the conglomerates are mostly of volcanic rock, but partly granitic material. Claystone makes up 10-15 percent of the section. Woody coal in beds less than 6 inches thick is found in the lower part.

Above the lower sandstone zone of the Nenana Gravel is a poorly consolidated conglomerate composed of well-rounded pebbles averaging 1-3 inches in diameter. The conglomerate has been found to consist of three zones on Sushana River: a lower 200-foot zone of pale yellow conglomerate with granite and white rhyolite pebbles; a middle zone of dark-gray and light-red pebbly graywacke; and an upper zone characterized by ophitic diorite pebbles, but containing a bed of abundant quartz and schist.

At the eastern end of the belt of Tertiary coal-bearing sediments is a small basin named the Jarvis Creek coal field. The following summary description of the field is taken from Wahrhaftig and Hickcox (1955, p. 353-366):

The Jarvis Creek coal field lies on the north side of the Alaska Range, between latitudes 63°35' and 63°45'N., and longitudes 145°40' and 145°50'W. It is 3 to 6 miles east of the Richardson Highway. The coal field is about 16 square miles in area, the major part of which is a rolling plateau that slopes gently northward and is bounded on the east, south and west by bluffs facing Jarvis Creek, Ruby Creek, and the Delta River.

The oldest rock is the Birch Creek schist of pre-Cambrian age, which is largely quartz-sericite schist with many quartz veins, and is locally intruded by rhyolite dikes. It is overlain by the Tertiary coal-bearing formation. Quaternary deposits include gravel, till, soliflectional debris, and windborne deposits.

The coal-bearing formation of the Jarvis Creek coal field is correlated with the lower member of the coal-bearing for-

mation on Healy Creek. In the south part of the coal field, it is divided into three stratigraphic units: (1) A basal lenticular bed, 500 feet in maximum thickness, consisting of micaceous sandstone and quartz conglomerate, derived from sources in Birch Creek schist southwest of the coal field: (2) a middle unit, 450 to 700 feet thick, or buff arkosic sandstone derived from areas north of the coal field, with interbedded shale and coal; and (3) an upper unit, about 900 feet thick, of dark-gray claystone, sandstone, and thin coal beds. The coal-bearing formation is warped into a north-trending structural basin. Dips around the border of the basin range from 5^{o} to 10^{o}.

Thirty coal beds were found, but most are thin and discontinuous. Reserves total 5.9 million tons of indicated coal and 7.5 million tons of inferred coal. Stripping reserves are estimated to be between 100,000 and 300,000 tons. The greater part of the coal reserves is in a 50-foot zone of coal and shale at the base of the middle stratigraphic unit. The coal field potentially contains about 75 million tons of coal. Based on outcrop samples, the coal has a heating value of between 8,000 and 9,000 Btu (as received) and an ash content of 5 to 13 percent. It is classified as subbituminous C.

A sandstone unit in the middle unit of the coal-bearing zone may be the most interesting part of the section for uranium investigations. Regarding this unit, Wahrhaftig (1955, p. 358) stated:

The abundant feldspar in the sandstone indicates that this unit was derived from a feldspathic terrain. Presumably, therefore, it came from the north or northeast, either from the granite of Granite Mountain (Moffit, 1942, p. 124) or from Totatlanika schist that may be buried beneath young Tertiary and Quaternary deposits in the Tanana Valley to the north (Capps, 1912, p. 22-26).

Tertiary sediments of the coal-bearing group and the Nenana gravel also lie in several basins within the boundaries of Mount McKinley National Park between 2,000 and 5,000 feet above sea level. These basins are shown on the eastern half of the geologic map of the Mount McKinley quadrangle and described in the text by Reed (1961, p. A18-A19; pl. 1). These Tertiary continental sediments rest unconformably upon pre-Tertiary rocks in broad basins and structural depressions. They are poorly consolidated to moderately consolidated and include conglomerate, sandstone, shale, and in some parts, subbituminous coal.

Another Tertiary nonmarine sedimentary unit present in the central part of the Alaska Range that has so far not been mentioned is the Cantwell Formation. This formation may be a favorable host for sedimentary uranium, but the most favorable portions lie within the boundaries of Mount McKinley National Park and it would be difficult to get a permit to explore or mine any deposits there (although Mount McKinley National Park is technically open to mineral development). The Cantwell Formation is discussed as separate section of this report.

Structure

The Birch Creek Schist basement is intensely deformed, tightly folded, and crumpled. In many places the bedding has been obliterated. The foliation strikes east and northeast and dips to the south. The Totatlanika Schist is generally less deformed than the Birch Creek Schist.

The uranium potential of the Tertiary coal-bearing group is of principal concern here, and therefore a discussion of the structure of this sequence is reproduced from Wahrhaftig and others (1951, p. 180-182):

> *The north flank of the Alaska Range is characterized by a series of broad eastward-trending folds, formed in middle Tertiary time, that are broken in places by both normal and reverse faults. The Tertiary rocks, including the Nenana gravel and the coal-bearing formation, are found in the troughs of the synclines, whereas schists and intrusive rocks older than the coal-bearing formation crop out in the cores of the anticlines. Through the center of the area under discussion passes a major syncline, which is bordered on the north by an anticline and on the south by a tilted fault block that forms the foothill range just south of the mapped area. The syncline, which is 10 to 15 miles wide at the Savage River, probably extends from the Mystic Creek coal basin on the east to the Toklat River on the west, a distance of 80 miles. It is marked by a series of basins that include some of the most economically important parts of the Nenana coal field. The western part of the syncline pitches 3^{o} E. In the area of this report the center of the syncline is characterized by very gentle dips, the beds in a belt 3 miles wide dipping less than 5^{o}. Along the north flank of the syncline, dips in the Nenana gravel are locally as high as 50^{o} but average between 30^{o} and 45^{o}. The belt of steeply dipping beds on the north limb of the syncline is less than 2-1/2 miles wide. The anticline to the north, like the syncline, is characterized by an axial belt 3 to 4 miles wide in which the beds are almost horizontal.*
>
> *Along the south flank of the major syncline, dips in the Nenana gravel range from 10^{o} at the Sushana River to 35^{o} at the Savage River. The structure in the Nenana gravel along the south flank is complicated by faults and minor folds. Steeply dipping strike faults repeat the contact between the Nenana gravel and Birch Creek schist just west of the Savage River. Minor domes and anticlines, at the centers of which Birch Creek schist is exposed, were found near the mouth of the Sanctuary River and east of the Savage River.*
>
> *Beds of the lower sandy zone of the Nenana gravel crop out on the east bank of the Teklanika River about 1-1/2 miles south of the mouth of the Savage River, which is nearly a half a mile south of their expected position. These beds are flat lying or dip gently northward. They appear to have been brought to their present position along the north flank of the syncline in a domed uplift.*
>
> *Because of the economic importance of the coal-bearing formation, and because it shows structural features not found in the Nenana gravel, the following discussion of its structure is added.*

The coal-bearing formation is exposed only on the south limb of the major syncline, between belts of Nenana gravel and Birch Creek schist. West of the Sanctuary River the coal-bearing formation dips 10°-20° N. and strikes N. 60°-80° E.; its attitude parallels that of the overlying Nenana gravel. A small reverse fault cuts a coal bed exposed in a tributary of the Sushana River, doubling its thickness in the outcrop. Dips as high as 55° N. were recorded at outcrops on the east bank of the Sanctuary River.

Throughout the greater part of the area of coal-bearing rocks in the Savage River basin, the dip of the beds is less than 15°. The prominent bed of basal conglomerate exposed along the south side of the area dips 20°-25° N., but the dip in overlying beds flattens rapidly northward. Along the north side of the basin the beds dip 5°-30° S.; vertical and overturned beds were observed at one outcrop on Sunday Creek.

One of the most pronounced structural features in Alaska is the Denali Fault, which coincides with the course of the Alaska Range and extends from southeastern to southwestern Alaska, a total distance of about 800 miles. Movement along the Denali Fault is believed to be right lateral, with little vertical displacement. Any interpretation of the source of the Tertiary sediments should consider the lateral displacement since early Tertiary time, which may be as much as 400 km (Smith, 1973, p. 25-27). Reed and Lanphere (1974, p. 1883-1891) show a displacement of 38 km between two plutons along the McKinley segment of the fault.

Igneous Rocks

A great variety of Paleozoic Mesozoic and Tertiary-age igneous plutonic and volcanic rocks are present in the Alaska Range. Paleozoic volcanic schist and intrusive greenstones, and tourmaline-bearing granite, granite, hornblende-biotite granodiorite, dunite, and quartz monzonite porphyry, for example, have been mapped in the northern foothills by Wahrhaftig (1970a-h). The Foraker and McGonagall plutons in the Mount McKinley quadrangle are among the larger intrusives bodies. These consist of granodiorite (Reed and Lanphere, 1974).

Economic Geology

Coal from the Tertiary coal-bearing group is the principal product of the northern foothills of the Alaska Range. Production at the Usibelli coal mine in the Healy Creek valley averages nearly 2,000 short tons per day. The reserves in the Nenana coal field are substantial. Coal has been mined at the Jarvis Creek coal field, but it has been inactive for many years.

The eastern part of the foothills belt is in the Bonnifield mining district; the western part lies in the Kantishna mining district (Berg and Cobb, 1967, p. 198-203; 229-231). Metal production from the Bonnifield district has been small, consisting of mainly of gold with subordinate amounts of silver from sulfide disseminations, veins, and pods in metamorphic rocks near felsic plutons. Silver, copper, lead, zinc, bismuth, and arsenic minerals are minor constituents. The best known deposit probably is the Liberty Bell mine near Eva Creek.

The Kantishna mining district is the area drained by the Kantishna River and its tributaries. It lies mostly in a group of foothills named the Kantishna Hills,

which are underlain by Birch Creek Schist. A number of lode deposits have produced small amounts of gold, silver, antimony, and lead ores from quartz veins. About 1,700 tons of metallic antimony were shipped from the Stampede Mine. Several deposits are within the boundaries of Mount McKinley National Park. The largest of these is on the north slopes of Mount Eielson, where massive argentiferous galena and other sulfides occur in limestone.

A locality of interest from the standpoint of uranium investigations is the Purky-Pile prospects, just outside the western boundary of Mount McKinley National Park on the west side of the headwaters of Boulder Creek, a small tributary of the Swift Fork of the Kantishna River. There are three separate prospects within about 3 miles of each other in metamorphosed sedimentary rocks near a small granite stock. The prospects have showings of silver, lead, zinc, and tungsten minerals (Maloney and Thomas, 1966). Six samples from the Mespelt prospect yielded anomalous eU values from 0.037 percent to 0.14 percent.

A small deposit of tarry bituminous material originally thought to be a petroleum seep is located 1 mile above the mouth of Cripple Creek, which flows northwest into Healy Creek. It is in gravels overlying the Tertiary coal-bearing group. Martin (1923, p. 137-147) concluded that the material is actually a coal tar produced by distillation from burning coal.

Radioactivity Investigations

The writer examined the Tertiary coal-bearing group in the Healy Creek valley with Geiger counters (Eakins, 1969, p. 12-13). The area was crossed at several points by walking up gullies so that each bed in the sequence was tested for radioactivity, and foot traverses were made along the entire 12-mile-long area where the coal-bearing beds were exposed. The maximum radioactivity in sandstones, shales, and the Birch Creek Schist was about 0.04 mr/hr, or three times the normal background. No radioactivity was detected at the site of the Delta coal mine at the head of Ober Creek in the Jarvis coal field (Eakins, 1969, p. 15). No other reports of investigations of the Tertiary coal-bearing group on the north flank of the Alaska Range are available. However, it was rumored that a private company was doing stream-sediment and water sampling for uranium in the Healy area last summer (1974), and that some anomalies were located.

Radioactivity tests of 50 rock specimens collected by the 1947 Bradford Washburn Mount McKinley expedition produced 0.009 percent eU in a manganiferous vein quartz sample; granitic rocks produced as much as 0.004 percent eU (Matzko, 1951; Wedow, 1956, p. 27). Veins in the Mount Eielson area and in the Kantishna Hills area did not produce over 0.001 percent eU (White and others, 1952, p. 7-9; Wedow, 1956, p. 28). Analyses of samples from the Mespelt prospect in the Purky-Pile group of prospects near the western border of Mount McKinley National Park are listed (Maloney and Thomas, 1966, table 3):

Sample		Oz/Ton		Percent						
No.	Description	Ag	Au	Pb	Bi	eU	Cu	Sb	Sn	W
6T	Thomas, 1959, grab of talus.	82.91	.01	46.4	-	-	0.42	2.52	-	-
7T	Thomas, 1959, chip of talus.	29.22	Tr	-	-	0.075	<.05	-	<0.03	0.01
8T	do.	1.87	Tr	-	-	.14	-	-	.06	.04
9T	Thomas, 1959, grab of talus.	1.75	Tr	-	-	.073	-	-	<.03	.02
10T	do.	10.71	Tr	-	-	.039	-	-	<.03	.03
11T	do.	.18	Tr	-	-	.037	-	-	<.03	.02

The reported eU values justify an investigation of the area. There has not been any production from the claims, though they have been held since 1921. An old 40-foot shaft on the Mespelt prospect is now caved in. A 7- by 5- by 15-foot shaft on the Jules-Knudson prospect was last reported full of water. A little trenching and road work by bulldozer is the only other work that has been done. The prospects are in a remote area of very rugged terrain.

Discussion

The Tertiary coal-bearing group along the north flank of the Alaska Range seems favorable as a uranium host rock, especially in the south-central portion where the beds are flat-lying, though they may be beneath a great thickness of Nenana Gravel in places. Volcanic ash beds within the sequence are a possible source of uranium.

The Tertiary Nenana Gravel is widespread in the province, and while it contains sandstone, conglomerate and some lignite, it may have been deposited too rapidly and flushed by ground waters to the extent that it is less favorable than the coal-bearing sequence; nevertheless, it should be examined.

The variety of Mesozoic and Tertiary intrusive rocks in the north slope of the Alaska Range may have supplied some favorable granitic material for the sedimentary rocks. Reed (1961), however, believes that the source of much of the material forming the coal-bearing group was to the north, rather than in the Alaska Range. The plutonic rocks could serve as host for vein-type deposits, especially in the vicinity of the Purky-Pile prospects, where the eU values were as much as 0.14 percent.

The Bonniville mining district includes silver, bismuth, copper, lead, zinc, and arsenic minerals, which are a favorable assemblege for vein-type uranium association. Apparently this district has not been investigated for radioactivity.

TANANA RIVER LOWLANDS

Three lowland areas along the Tanana River in central Alaska have been designated as (1) upper Tanana Basin, (2) middle Tanana Basin, and (3) lower Tanana Basin (Miller, Payne, and Gryc, 1959, p. 82-87, pl. 2). These occupy 3,000, 6,500, and 2,500 square miles, respectively. The lower Tanana Basin is somewhat misnamed, because, while its upper end is on the Tanana River, it is located principally along the Yukon River, just below its confluence with the Tanana River. The lowlands are bounded on the north by the Yukon-Tanana highland and the Ray Mountains, and on the south by the northern foothills of the Alaska Range.

The lowlands are basins of rivers that have very large flows; the source areas for the thick Cenozoic gravels, sandstones, and alluvium are widely distributed over the central part of the state. Nonmarine Tertiary sediments, which may in part be the continuation of the coal-bearing group on the north flank of the Alaska Range, rest on Precambrian or Paleozoic schists and are overlain by Quaternary alluvium. The extent and thickness of Tertiary deposits in the lowlands are for the most part unknown. Basement rock is exposed in scattered outcrops and aeromagnetic surveys indicate they are at shallow depth south of Fairbanks.

Little subsurface information is available on the sediments, but one deep well, the Union Oil of California Nenana No. 1, was drilled to 3,062 feet 17 miles west

of Nenana townsite in 1962. A 600-foot section of Tertiary rock was measured in the bluffs near the middle of the lower Tanana Basin.

These lowlands are generally underlain by numerous isolated masses of permafrost. The maximum depth to the base of permafrost is 265 feet, near Fairbanks (Ferrians, 1965). Temperatures range from -76°F to +100°F in the Tanana basin. The mean yearly temperature at Big Delta is 27.5°F.

The generalized geology of the Yukon-Tanana upland is shown in figure 65, and the most highly mineralized districts are indicated in figure 66.. The general geology and ground water in the Tanana basin between the Canadian border and Tanana are published in a hydrologic atlas (Anderson, 1970).

The following geologic description of the upper Tanana Basin (termed the Northway-Tanacross lowland) is from Gates, Grantz, and Patton (1968, p. 44):

> *The Northway-Tanacross lowland is along the south side of the upper Tanana River, between the eastern Alaska Range and the Yukon-Tanana upland (Fig. 5). The lowland ranges in width from less than 10 to as much as 30 mi and is about 100 mi long; areas of low relief underlain by glacial, alluvial, swamp, and lake deposits cover roughly 1,500 sq. mi of its floor. Reconnaissance geological surveys summarized by Mertie (1937) and Moffit (1954a) indicate that the outcropping rocks at the margins of the lowland which may also underlie it, consist of low- and intermediate-grade metasedimentary and metavolcanic rocks of Precambrian(?) and Paleozoic ages. These rocks contain a variety of intrusive and metasomatic granitic rocks and they are unfavorable for petroleum.*
>
> *Seismic surveys (D.F. Barnes, oral communication, 1963) suggest that the surficial deposits which underlie the lowland may be 1,000 ft. in thickness. Two wells 200 and 350 ft. deep, drilled entirely in the surficial deposits, yielded small flows of swamp gas (methane with a trace of higher hydrocarbon gases). In the quantities probably available, the gas in the surficial deposits is not considered to be economically significant.*
>
> *The only chance for a petroleum resource (methane gas) lies in the possibility that a large body of Tertiary coal-bearing rocks, such as underlies the north side of the Alaska Range on the west, was overlooked by the reconnaissance surveys or underlies the lowland but is unexposed. An aeromagnetic survey of the eastern tip of the lowland indicates that this part is underlain at shallow depth by the unfavorable Paleozoic rocks. There is thus no positive evidence that a body of potentially petroliferous rocks underlies the lowland, and the presence of such a body that is thick and extensive is judged to be geologically improbable.*

A discussion of the middle Tanana basin with a view of the petroleum possibilities is also taken from Gates, Grantz, and Patton (1968, p. 43-44):

> *The Tanana lowland is between the Tanana River and the Northern Foothills of the Alaska Range from Gerstle River on the east to the Kantishna River drainage on the west. The lowland is amoeboid in outline, 10-50 mi wide, and 200 mi long.*

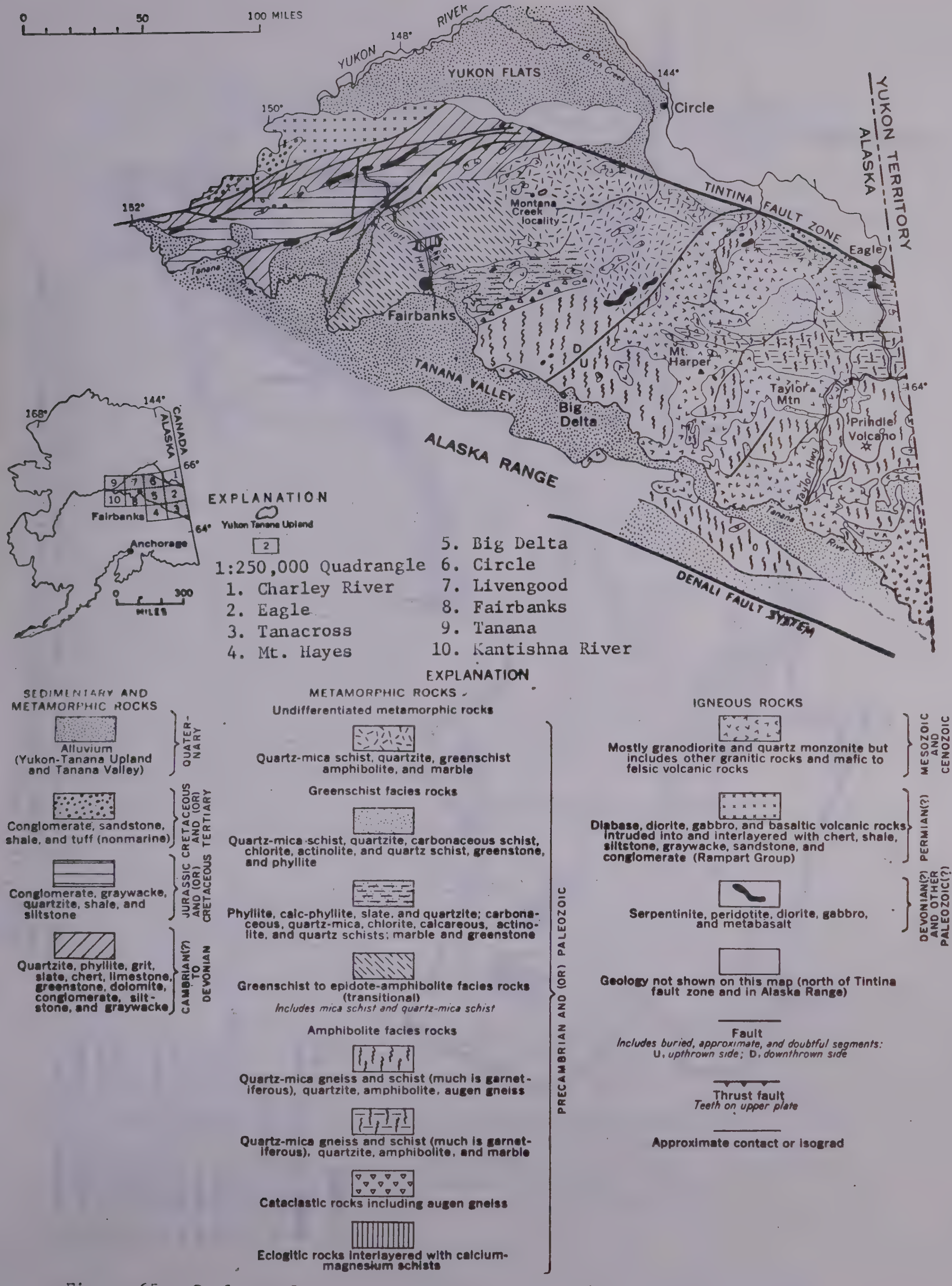


Figure 65. Geology of the Yukon-Tanana upland. (Source: Foster and others, 1973.)

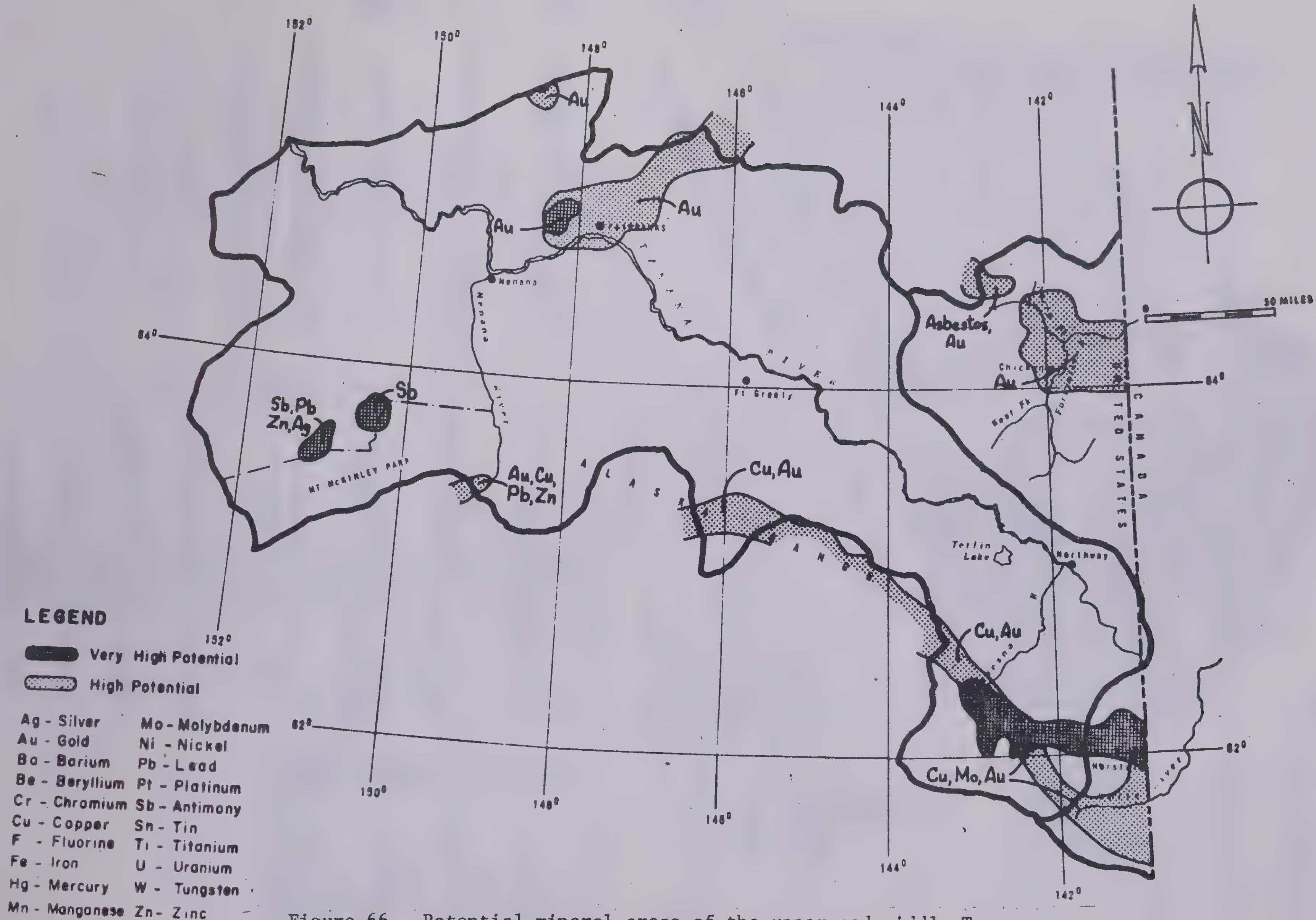


Figure 66. Potential mineral areas of the upper and middle Tanana Basin. (Source: Federal-State Land Use Planning Commission, Yukon Region, fig. 38.)

It is underlain by glacial, alluvial, swamp, and lake deposits of Quaternary age in an area of approximately 6,000-7,000 sq mi. These deposits are at least 750 ft and possibly as much as 1,000 ft thick east of Nenana, and are possibly as much as 1,800 ft thick beneath part of Minto Flats (D.F. Barnes, 1961; oral communication, 1963). The reconnaissance geology of the region has been summarized by Mertie (1937), Moffit (1954), and Capps (1940), and more detailed reports on part of the region have been prepared by Wahrhaftig (1958) and Reed (1961).

At most places the lowland is bordered by very low-grade to intermediate-grade metasedimentary and metavolcanic rocks which contain granitic intrusive rocks at many places and are of Precambrian(?), Paleozoic, and Cretaceous ages. At the southern margin, however, the lowland is bordered in many places, and also underlain, by coal-bearing rocks and nonmarine gravels of Tertiary age that overlie the older rocks with nonconformity. These Tertiary rocks are clastic basin deposits; they are at least 5,000 ft thick in the Northern Foothills of the Alaska Range, but thin northward to 1,000-2,000 ft where they reach the southern edge of the Tanana lowland. No tectonic relationship between the Tertiary basins and the present Tanana lowland and its thick Quaternary deposits is evident.

Present information indicates that the petroleum resource potential of the Tanana lowland is limited to the possible presence of natural gas (methane) in the Tertiary nonmarine rocks. Accumulations of swamp gas probably are present in the thick and extensive Quaternary deposits, but their potential is considered to be slight at best. The pre-Tertiary rocks which can be inferred geologically to underlie the lowland are either igneous or have been metamorphosed to some degree, and therefore are not considered to have potential for petroleum deposits.

Masses of Tertiary nonmarine sedimentary rocks of sufficient size to constitute a source of commercial gas deposits may underlie some areas of the lowland, but in other areas the possibility of their presence seems to have been eliminated by geological or geophysical data. The area most likely to be underlain by a large body of Tertiary nonmarine rocks tends south by west from the Minto Flats to the Northern Foothills of the Alaska Range, and is about 1,300 sq mi. It is delineated by low gravity values (Barnes, 1961). A slim hole drilled in 1962 to test the gravity anomaly reportedly penetrated Tertiary nonmarine rocks to a depth near 3,000 ft, where it entered pre-Tertiary basement. On the basis of recent data, Barnes (oral communication, 1963) estimates that almost a mile of Tertiary rocks may underlie part of the area.

The central part of the Tanana lowland contains scattered outcrops of pre-Tertiary basement rocks, and an aeromagnetic survey indicates that these basement rocks are at shallow depth in much of the area south of Fairbanks. Therefore, it is thought that little or no Tertiary sedimentary

rock underlies this part of the lowland. The eastern part of the lowland, however, may be underlain in places by Tertiary nonmarine rocks, for such rocks are present along its border with the Alaska Range, although no Tertiary rocks crop out outside of the lowland itself.

The Tanana lowland is a possible petroleum province because it may contain natural gas in Tertiary nonmarine rocks, but it is less promising for gas than the Tertiary rocks of the Cook Inlet area and other thick Tertiary basins in coastal southern Alaska. Neither the presence of commercial gas deposits nor the presence of a really thick section of favorable rocks has been demonstrated in the Tanana lowland. However, if small commercial gas deposits could be located, markets probably would be available in the Fairbanks area and in the sizable military establishment in the lowland.

The following summary of the lithology of the sediments in the western part of the middle Tanana basin (sec. 7, T. 4 S., R. 10 W.) is condensed from the baroid log of the Union of California No. 1 Nenana well:

Depth (ft)	Lithology
300-1,050	Predominantly sand with mixed coal, volcanics, tan ash, and a little basalt.
1,050-1,100	Predominantly sandstone, partly conglomeratic.
1,100-1,750	Predominantly sandstone.
1,750-2,380	Sandstone, shale, some chert, lignite, wood, volcanics, and clay.
2,380-2,770	Volcanic ash and coal.
2,770-3,062	Schist, with some bentonite, clay, and pyrite.

The geology of the middle Tanana basin is shown on maps by Pewe and others (1966), Andreasen and others (1964), and Wahrhaftig (1970a-h).

The following discussion of the lower Tanana Basin is from Miller, Payne, and Gryc (1959, p. 82-83):

The lower Tanana basin is occupied by the Yukon River between Tanana and Ruby, by the part of the Tanana River below Cosna, and by the lower course of the Nowitna River, which enters the Yukon from the south. It has an area of about 2,500 square miles and is contained in the Kantishna, Ruby, Tanana, and Melozitna quadrangles.

The middle part of the basin is only 10 miles in width, and here, at what is known as the Palisades, deposits of Tertiary and Quaternary age have been incised by the Yukon and are exposed in bluffs as much as 250 feet in height. At this locality Eardley (1938, p. 318) measured about 600 feet of Tertiary, 200 feet of Tertiary or Quaternary, and about 430 feet of Quaternary beds. The total thickness of the Tertiary sequence is unknown because the base was not seen; it consists of woody lignite in beds up to 20 feet thick, somewhat compacted loam, and slightly cemented sandstone. The Tertiary beds are tilted and form the

upthrown block of a fault that has brought them into juxtaposition with the Quaternary deposits. The Tertiary or Quaternary sequence is exposed farther downstream in the Palisades, is flat-lying to gently tilted, and consists of beds of sandstone and conglomerate, gravel, sand, silt, and loam.

The Tertiary rocks may be of early Tertiary age and equivalent to the nonmarine rocks of the Healy trough and other troughs of central Alaska. If this correlation is correct, then the overlying strata regarded by Eardley as of Tertiary or Quaternary age may be entirely of Tertiary age and perhaps equivalent to the Nenana gravel of the Healy trough and Alaska Range area. On the other hand, the woody character of the lignite in the Tertiary unit and the relatively unconsolidated nature of the sand and loam suggests that the beds may be of late Tertiary age, in which case the overlying unit represents basal Quaternary deposits. In either case the order of events at this locality evidently was as follows: (1) deposition of Tertiary rocks, (2) folding or at least strong tilting, (3) erosional truncation of these rocks, (4) deposition of Tertiary or Quaternary rocks, (5) deposition of Quaternary rocks, (6) faulting, with a throw of at least 200 feet, and further gentle tilting of the beds, (7) erosional truncation to form the present basin surface, and (8) uplift and entrenchment of the Yukon River to form the Palisades.

Although there is no evidence of marine deposits of Tertiary age in this province, the presence of such deposits cannot be ruled out, because the thickness and character of Tertiary beds underlying the exposed section are unknown, and the exposures are limited to such a small part of the basin province. The possibilities of finding oil in pre-Tertiary rocks are not good because they evidently consist of metamorphic rocks of the Ruby geanticline and of the part of the Kuskokwim geosyncline adjacent to the basin. Seeps have not been reported in this basin.

Investigations for radioactivity in the region of the Tanana basins have consisted or reconnaissances along the Richardson and Alaska Highways and the Tanana River. Granitic rocks and mining properties in the bordering Yukon-Tanana Upland and the northern foothills of the Alaska Range were tested in a number of areas.

An investigation of the exposures along the Tanana River from Tanacross to the mouth of Little Crestle River was conducted by White, Nelson, and Matzko (1963, p. 81-82, fig. 16). The maximum radioactivity noted along the traverse was from granite near Cathedral Bluffs, which contained 0.006 percent eU.

Wedow and Matzko (1947, p. 27, 55-57) reported 0.004 percent eU from granite and 0.02 percent eU from the heavy-mineral fraction from a placer deposit in the Harding Lake-Richardson area. The same authors (p. 36-63) reported as much as 0.011 percent eU from the heavy-mineral fraction from gravels in Ober Creek, in the Jarvis coal field area south of the Tanana River.

Results of sampling along the Alaska Highway and the Tanana River and in the Fairbanks district are reported by Wedow, Kileen, and others (1954). Concentrates from granitic areas near Fairbanks produced up to 0.100 percent eU.

The Slana-Nabesna and Chisana districts in the eastern Alaska Range were investigated for radioactivity by Nelson, West, and Matzko, (1954, p. 2-7). Only three of the samples collected contained 0.003 percent or more eU, and the radioactivity of these samples was due principally to the accessory minerals, sphene and zircon.

The uranium potential of the Tanana basins is problematical. Nonmarine Tertiary sandstones, volcanic ash, and coal are known to be present, but their extent in the subsurface is not known. The source of the Tertiary sediments may have been as far distant from the lowlands as Livengood; some of the source areas contain granitic rocks.

It seems to this writer that the factor most unfavorable to the occurrence of sedimentary uranium in this region is the very shallow water table in the valleys, which is from 0 to 50 feet.

PHOSPHATE DEPOSITS IN NORTHERN ALASKA

Uranium can be produced as a by-product of phosphate production from natural phosphate rock. Because of its above-average uranium content for a sedimentary rock, all phosphate rock deposits are a potential low-grade source of uranium.

Deposits of sedimentary phosphate rock of Mississippian and Triassic ages occur on the Arctic Slope along the northern flank of the Brooks Range. The phosphate beds have been found at widely scattered localities, but their true extent and thicknesses are not known, since the region has not been mapped in detail. Patton and Matzko (1959) have reported on these deposits, and the abstract of their report is reproduced here:

> *Deposits of sedimentary phosphate rock were discovered on the Arctic Slope of Alaska during the geologic investigation of Naval Petroleum Reserve No. 4 between 1944 and 1953. They occur in at least two stratigraphic units, the Lisburne group (Mississippian) and the Shublik formation (Triassic), and have been found at widely scattered localities along the north front of the Brooks Range and in the adjoining foothills. The deposits in the Lisburne group in the central Brooks Range and Arctic foothills are of principal interest and have been examined in detail and systematically sampled at two localities, Tiglukpuk Creek and upper Kiruktagiak River.*
>
> *The Tiglukpuk Creek and upper Kiruktagiak River areas are underlain by a thick sequence of highly deformed sedimentary rocks uncluding the Wachsmuth limestone and Alapah limestone of the Lisburne group (Mississippian), the Siksikpuk formation (Permian?), the Shublik formation (Triassic), and the Tiglukpuk formation (Jurassic). The phosphate deposits are confined to the black chert and shale member of the Alapah limestone, near the top of the Lisburne group. This member, which ranges from about 40 to 100 feet in thickness, consists chiefly of dark shaly limestone, mudstone, and phosphate rock; it forms*

a distinctive lithologic unit within the massive light-colored fossiliferous clastic limestone that comprises the bulk of the Lisburne group which ranges in thickness from 2,000 to 2,500 feet.

The uraniferous phosphate rock from northern Alaska contains carbonate-fluorapatite as the phosphate mineral and, in general, is similar in mineralogy, phosphate, uranium, and minor element content to phosphates from the Phosphoria formation of Permian age in Northwestern United States. Other minerals identified are calcite, dolomite, quartz, and purple and colorless fluorite. Carbonaceous matter stains all the phosphate rock.

In the Tiglukpuk Creek area the phosphatic zone in the black chert and shale member is 36 feet thick and averages 8 percent P_2O_5. A 43-inch sequence of rock 16 feet below the top of the zone averages 21 percent P_2O_5. In the upper 20 feet of the zone 6 beds, from 1 to 5.5 inches thick, contain 30 percent P_2O_5. In the upper Kiruktagiak River area the phosphate zone is 38 feet thick and averages 12 percent P_2O_5. The upper 19 feet averages 19 percent P_2O_5; one 27-inch sequence of rock 16 feet below the top contains 27 percent P_2O_5. Because of the marked lateral variation in lithologic character and phosphate content in the black chert and shale member and the complex structure of the central Brooks Range and Arctic foothills, much work remains to be done before the phosphate deposits can be fully evaluated.

Samples containing as much as 35.8 percent P_2O_5 have been collected from the Shublik formation at several localities in the eastern Brooks Range. These deposits have not been sampled and measured systematically; therefore nothing is known of their thickness and extent.

Numerous analyses of the phosphate and radiometric contents of the phosphate-bearing units appear in the report by Patton and Matzko. The highest eU content found was 0.022 percent, in the Lisburne group (Patton and Matzko, pl. 4). Results of phosphate and radiometric analyses of 38 selected samples are given below (Patton and Matzko, p. 11-12):

Analyses of samples

Sample No.	Rock	Percent			
		P_2O_5 [1 2 3]	V_2O_5 [6 7]	Equivalent U [4]	U [5]
Lisburne group					
45AGr21	Phosphate rock	[2] 25.6	[6] 0.02	0.009	------
48ASa35	Limestone	[1] <5	----------	<.001	------
48ASa48	Shale	[1] <5	----------	.002	------
49ALa8	Limestone and mudstone	[1] <5	----------	<.001	------
49ADt131	Phosphatic limestone	[3] .4	----------	.004	------
50ATr61	Phosphate rock	[3] 24.8	[7] .17	.008	------
50ATr[illegible]	Limestone	[1] <5	----------	.001	------
50ATr160	Phosphatic mudstone	[3] 13.7	----------	----------	0.004
50AKt89	Shale	[1] <5	----------	<.001	------
50ACh53	Limestone	[1] <5	----------	.001	------
50ACh[illegible]	Siltstone	[3] 1.4	----------	.005	------
50AKe279	Phosphate rock	[3] 27.9	----------	.020	------
50APa258	Limestone	[1] <5	----------	.008	------
50ABo76	Phosphate rock	[1] 15±	----------	.009	------
50ABo78	do	[2] 21.4	----------	.014	------
51ARr111	Siltsone	[1] <5	----------	<.001	------
51ARr125	Shale	[1] <5	----------	.002	------
51ARr131	do	[1] <5	----------	<.001	------

Shublik formation					
48ASa98	Limestone	[1] <5	----------	<0.001	------
48ASa110	Siltstone	[1] <5	----------	.003	------
48ASa222	Phosphate rock	[1] 20±	----------	.004	------
48ASa223	Limestone	[1] <5	----------	.002	------
48ASa225	do	[1] <5	----------	.002	------
48AWh86	Phosphatic siltstone	[1] 10±	----------	.003	------
48AWh87	Shale	[1] <5	----------	.001	------
48AWb89	Phosphate rock	[1] 15±	----------	.003	------
48AWh123	do	[2] 18.4	----------	.003	------
48AWh137	Phosphatic limestone	[1] 5±	----------	.002	------
50AGr38	Phosphate rock	[3] 14.7	----------	----------	0.001
50AGr44	Limestone	[3] 1.55	----------	----------	.001
50APa245	do	[1] <5	----------	<.001	------
51AGr11	Phosphate rock	[3] 35.8	----------	----------	.008
51AKe11	Siltstone	[1] 5±	----------	.001	------
Kingak shale					
48ASa217	Sandstone	[1] <5	----------	0.002	------
Stratigraphic position uncertain					
48ASa22	Phosphate rock	[3] 22.0	----------	0.007	------
49ADt41	Mudstone	[1] 5±	----------	.004	------
50ALa257	Siltstone	[1] <5	----------	<.001	------
51ASa36	do	[2] .2	----------	.002	------

[1] J. J. Matzko, analyst; P_2O_5 determined by rapid field test, U. S. Geological Survey, College, Alaska.
[2] Audrey Smith, analyst; P_2O_5 determined by laboratory analysis, U. S. Geological Survey, Washington, D. C.
[3] J. W. Budinsky, analyst; P_2O_5 determined by laboratory analysis, U. S. Geological Survey, Washington, D. C.
[4] J. J. Matzko, analyst.
[5] J. W. Budinsky, analyst.
[6] Robert Meyrowitz, analyst.
[7] F. S. Grimaldi and J. J. Warr, analysts.

Many additional radiometric analyses are recorded in the same report on plates 3 and 4. Although some of the phosphate rock is high grade, the locations of the deposits preclude any possibility of their development at this time.

PRECAMBRIAN GNEISSES IN THE GOODNEWS QUADRANGLE, SOUTHWESTERN ALASKA

Precambrian metamorphic rocks in the southern Kuskokwim Mountains extend 53 miles in a northeast-trending belt from a point near the coast of Kuskokwim Bay, about 16 miles north of Goodnews Bay to the northern edge of the Goodnews quadrangle (fig. 67). The midpoint is approximately 60 miles south of the town of Bethel. The general area is sometimes referred to as the Kenektok district after the Kenektok River, which flows east-west across the metamorphic belt.

The metamorphic complex is of special interest to uranium resource investigations because it is definitely of Precambrian age and in part consists of gneisses of granitic origin. The distribution of these rocks and the general geology in the Goodnews quadrangle is shown on the geologic map by Hoare and Coonrad (1961); a description of the Precambrian rocks that accompanies their map is quoted:

> *A metamorphic complex, p€m, crops out in the northwest corner of the quadrangle from near Jacksmith Bay northeast to north edge of the quadrangle. It is predominantly a sequence of highly metamorphosed sedimentary and volcanic rocks but probably includes some recrystallized intrusive rocks. Pink and gray gneiss and light- to dark-gray schist form most of the complex. White crystalline limestone, quartz-muscovite schist, and black garnetiferous amphibolite constitute a minor part of the complex.*

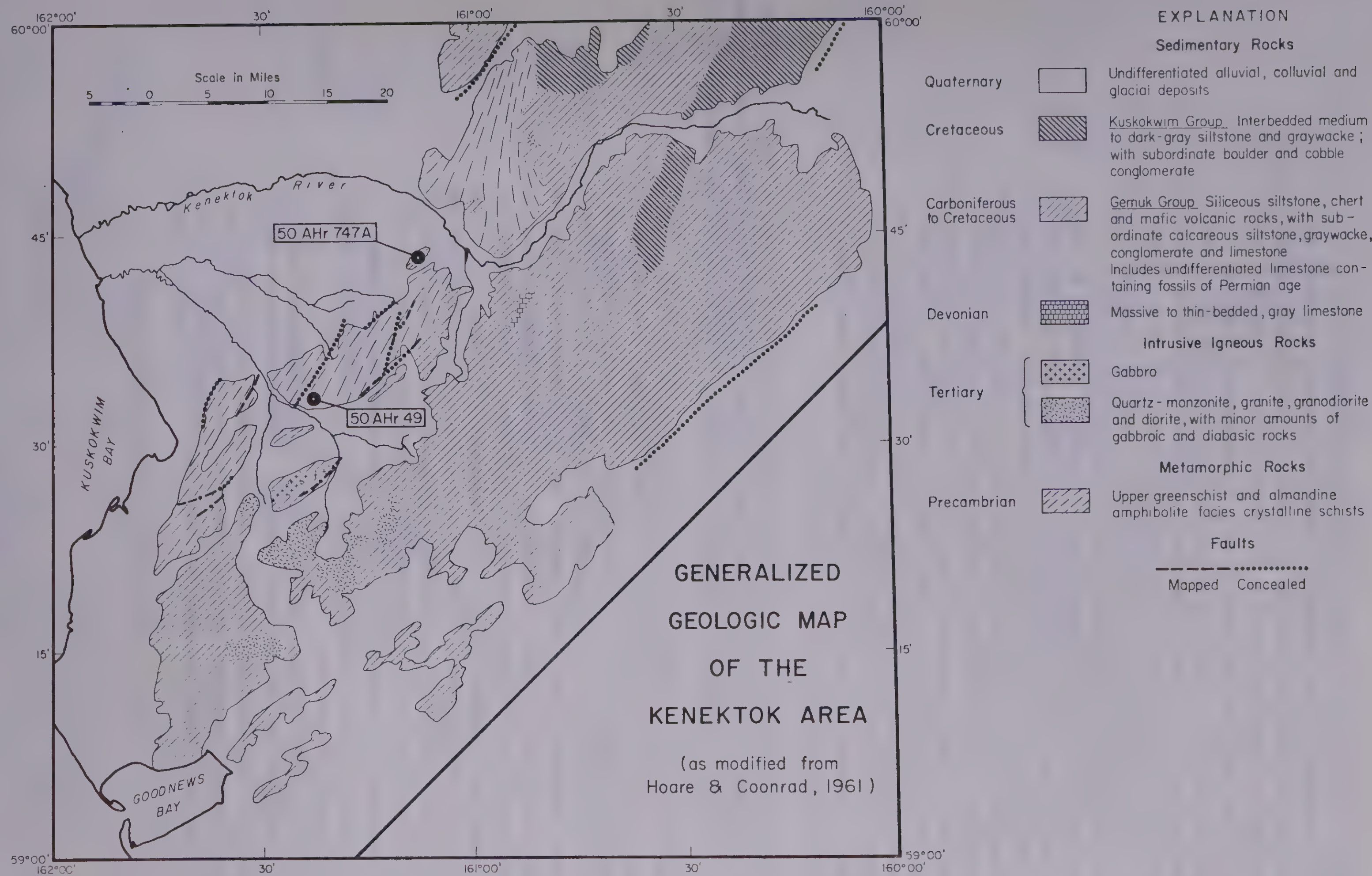


Figure 67. Generalized geologic map of the Kenektok area. (Source: Forbes, Turner, and Hoare, 1975.)

Most of the gneiss shows a well-developed foliation, which is assumed to be bedding-plane foliation because it is parallel to bedding planes in nearby limestone. Some of the schistose rocks show a well-developed lineation resulting from parallel orientation of amphibole needles.

The attitude of the foliation and lineation indicates that the rocks are tightly folded and that they tend northeastward parallel to their outcrop pattern and to the regional strike. Near the north edge of the quadrangle, isolated patches of siltstone and conglomerate of Cretaceous age overlie the gneiss and schist. Farther north in the adjoining Bethel quadrangle isolated exposures of gneiss and schist are surrounded by broad areas underlain by sedimentary rocks of Cretaceous age. Most of the rocks that comprise the metamorphic complex are thought to be Precambrian in age, because they are much more metamorphosed than limestone of Devonian age, which crops out south of Kanektok River, and they are lithologically similar to rocks that elsewhere in Alaska are considered to be Precambrian. However, the unit probably includes some small areas of Paleozoic rocks.

Recent work by Forbes, Turner, and Hoare (1975) has produced more positive Precambrian age dates for the complex, petrographic classifications, and tectonic implications. The following information has been furnished by the above authors:

The Kennektog Complex, which occurs as a narrow, discontinuous outcrop belt of crystalline schists northeast of Goodnews Bay, Alaska, has yielded $^{40}K/^{40}Ar$ hornblende ages of 1078 ± 32 and 533 ± 16 (1σ) m.y. and a biotite age of 437 ± 13 m.y. These data suggest that the complex is of Precambrian age and has been subjected in part to thermal overprinting during an Ordovician or later thermal event. Although infra-Cambrian and/or Beltian sedimentary rocks are known to occur at a few localities in north-east Alaska, and a late Pre-Cambrian Rb-Sr whole rock isochron age has been reported for Seward Peninsula paragneisses, the Kennektog Complex is the first Alaskan terrane to yield $^{40}K/^{40}Ar$ dates suggesting a Precambrian age and may represent the oldest sequence of rocks yet discovered in Alaska.

Our subsequent detailed petrographic studies of the collections made by Hoare and Coonrad, show that the complex includes metamorphic rocks of the upper greenschist and lower almandine amphibolite facies, and mafic and granitic intrusive rocks, as outlined in Table 1.

Table 1. Kennektok Complex Rock Types.

Crystalline Schists	*Intrusive Rocks*
garnet amphibolites	*hornblendites*
epidote amphibolites	*granodiorite*
biotite-hornblende gneisses	
biotite-muscovite orthoclase gneisses	

Table 1. (Cont.)

Crystalline Schists
biotite paragneisses
calc-mica schists
quartz-mica schists
biotite clinozoizite schists

The discovery of a Precambrian metamorphic terrane in Southwest Alaska, which also contains an accompanying record of a subsequent Ordovician or later thermal event, will apply new constraints to present and future Alaskan tectonic models and reconstructions. The tectonic position of the Kennektok complex is difficult to explain, based on our current knowledge of the basement tectonic framework, including the age and regional distribution of other Alaskan metamorphic belts.

Based on structural elements, stratigraphic evidence and outcrop belt trends, extensions of this same complex are most likely to be found to the northeast in the metamorphic terranes of the Kaiyuh Hills and the Yukon-Koyukuk Uplands.

THE NORTH SLOPE

The North Slope of Alaska is the vast, California-size region north of the Brooks Range. It extends 600 miles from the Canadian border west to the Chukchi Sea, and is as much as 200 miles wide from north to south (fig. 68). The region is now well known for containing one-third of the nation's petroleum reserves and for the pipeline being constructed from Prudhoe Bay to Valdez.

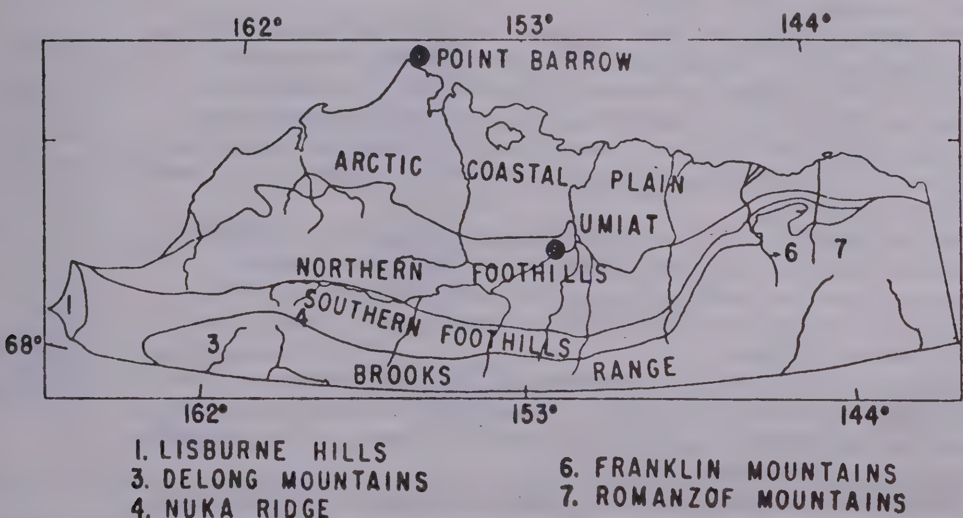


Figure 68. Physiographic provinces of northern Alaska. (Source: Gryc, 1970, p. C5.)

The North Slope, also known as the Arctic Coastal Plain, is a smooth, poorly drained, recently emerged plain rising gradually from the Arctic Ocean to a maximum of 600 feet at its southern margin defined by the northern foothills of the Brooks

Range. The region is entirely north of the Arctic Circle and is underlain by continuous permafrost which extends to depths of as much as 2,000 feet (Lachenbruch, 1970, p. J1). The surface is marshy and lake-dotted. The mean annual temperature at Barrow is 9.6°F, and the annual precipitation is 4.26 inches (Searby, 1968, p. 8).

Paleozoic and Mesozoic sediments form thick and varied sequences across the North Slope. Most of the sediments are of marine origin, but parts of the Late Cretaceous age sequence are nonmarine and contain volcanic ash beds and carbonaceous units. The Tertiary sediments in the eastern part of the region are up to 7,000 feet thick and contain nonmarine and nearshore sandstone and coal. The Late Cretaceous and Tertiary age rocks seem to contain the favorable type lithologies for sedimentary-type uranium deposits. The generalized geology of northern Alaska is shown in figure 69, and a generalized stratigraphic column of the Prudhoe Bay oil field is shown in figure 70.

The following outline of the North Slope stratigraphy is from a paper by Tailleur (1969):

> *The interpretable record begins in the Silurian or Devonian. From then into the Jurassic, sediments were deposited in a basin that spread at least 450 miles south of Barrow.*
>
> *Argillite forms the pre-Mississippian basement in the coastal wells. Except for an area of Devonian carbonate rocks (the Baird group), clastic and interlayered clastic and carbonate rocks lying unconformably beneath Mississippian rocks in the Romanzof Mountains have been mapped collectively as the Neruokpuk formation. The Neruokpuk has been assigned a Devonian or older age; it probably is older than the adjoining Devonian Baird group.*
>
> *The Baird group and the Lisburne group (productive in Prudhoe) consist of Devonian and Carboniferous carbonate rocks that accumulated offshore in the Arctic Alaska basin.*
>
> *The Baird group is reefoid in part. The Lisburne becomes younger to the north. The Endicott group includes the Devonian and Mississippian clastic rocks that were deposited nearer shore.*
>
> *The carbonate rocks of the Lisburne group are succeeded to the south by the thin shale and chert of the Permian Siksikpuk formation and to the north and northeast by the clastics of the Permian and Triassic Sadlerochit formation (productive in Prudhoe).*
>
> *The upper part of the Sadlerochit is equivalent in time to the lower part of the Shublik formation in the south. Thin deposits of the Middle and Upper Triassic parts of the Shublik blanket most of the North Slope.*
>
> *The Shublik is overlain by similar deposits of Early and Middle Jurassic age in the south, by the Jurassic Kingak shale in the northeast, by a similar shale in the far west, and by Triassic(?) and Lower and Middle Jurassic sandstone (gas at Barrow, shows in Colville Well) in the north.*
>
> *The Kemik sandstone member of the Okpikruak formation near the Jurassic-Cretaceous boundary in the northeast could represent the last of the coarse detritus shed into the Arctic Alaska basin from the north.*

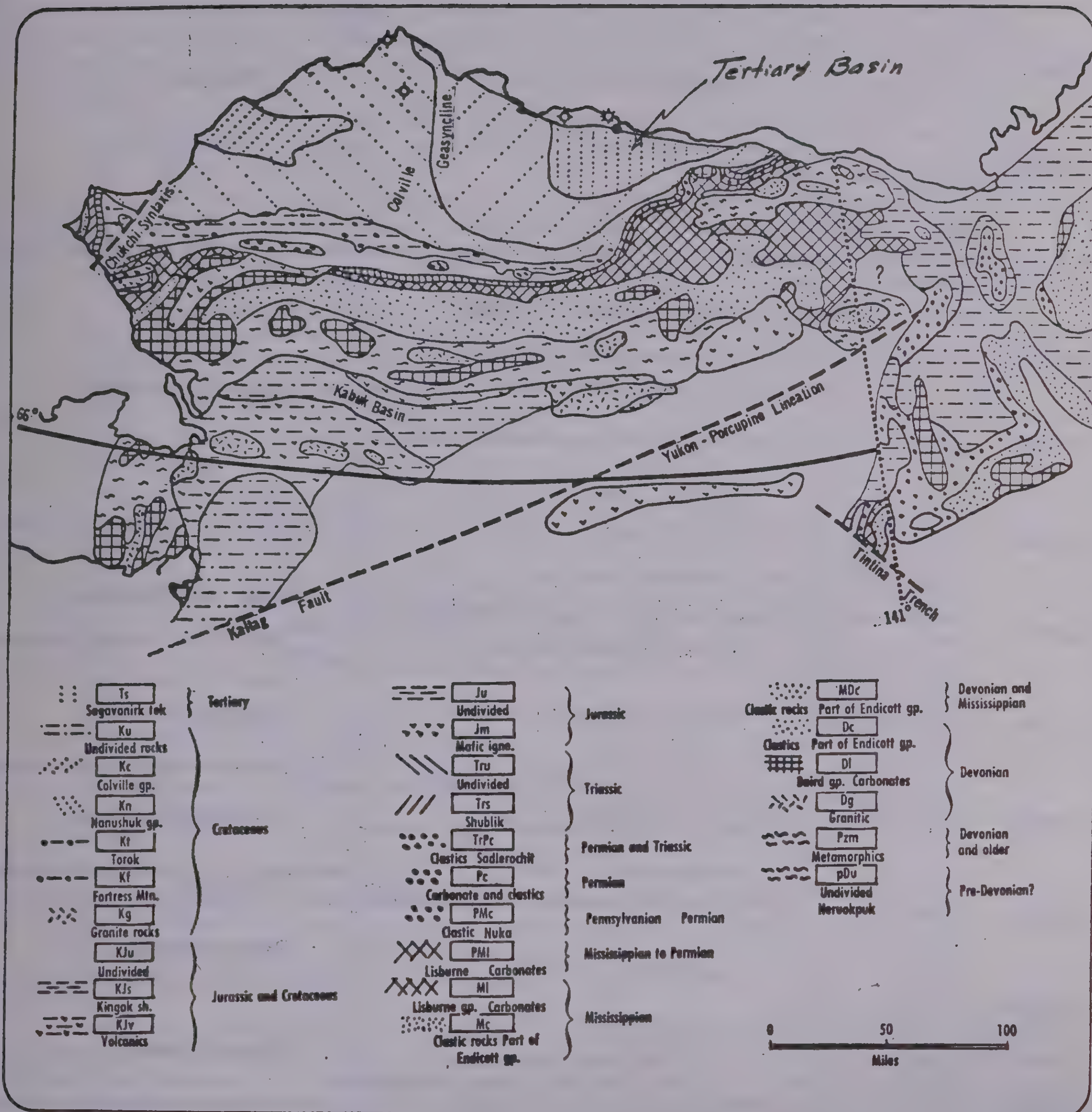


Figure 69. Generalized geology of northern Alaska. (Source: Tailleur, 1969, p. 216.)

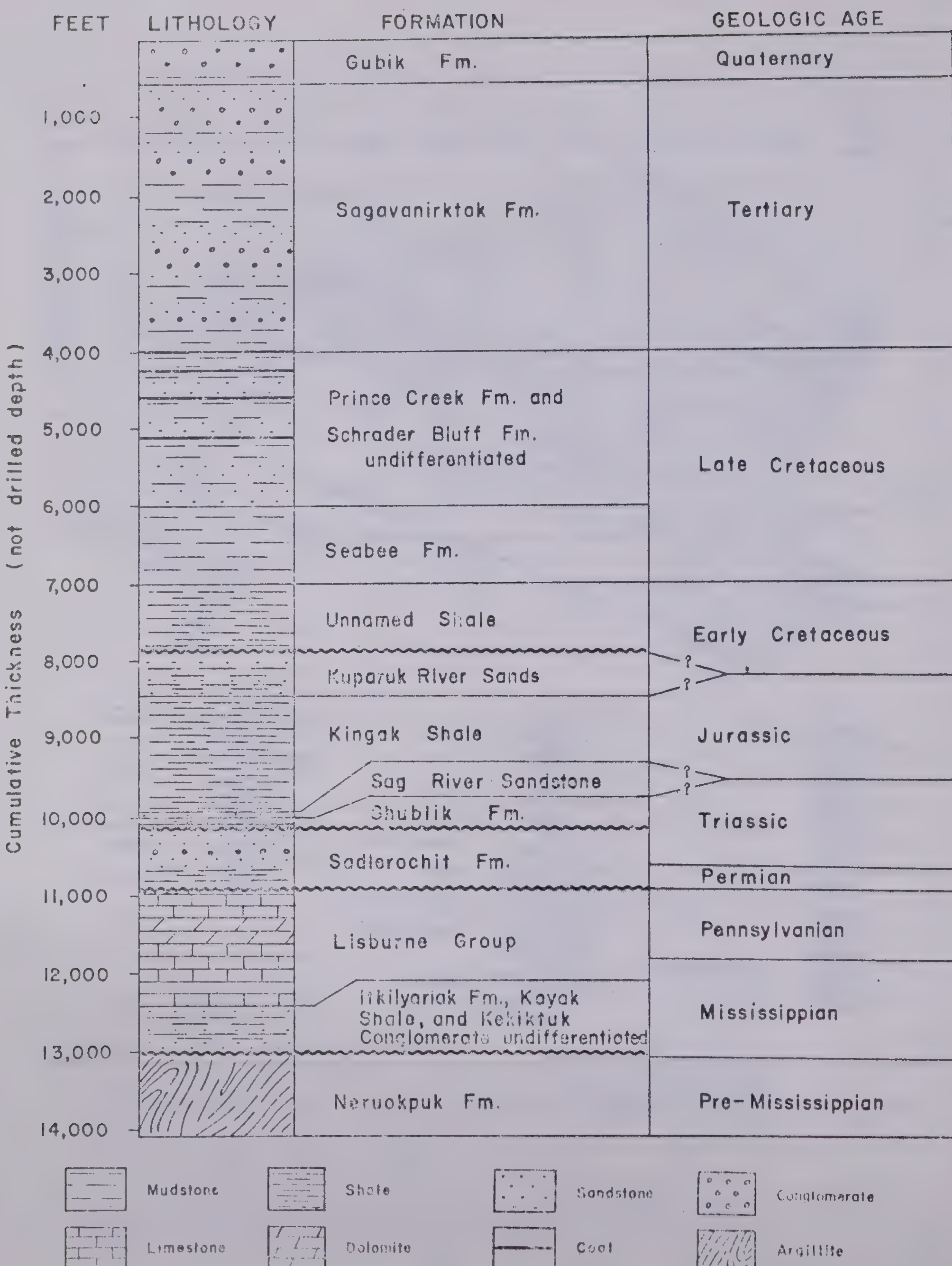


Figure 70. Generalized stratigraphic column of Prudhoe Bay field. (Source: Alaska State Div. of Oil and Gas, 1974.)

In the south, mafic intrusives and extrusives, volcanogenic chert, shale, and oil shale formed in Jurassic time during the initial stage of the orogenic era.

Earliest Cretaceous (Neocomian) deposits consist of orogenic graywacke and mudstone of the Okpikruak formation grading into shale and coquina and then pebble shale to the north.

Lower Cretaceous (Albian) orogenic deposits (penecontemporaneously deformed) make up the Fortress Mountain and lower Torok formations.

The Lower and Upper Cretaceous Nanushuk and Upper Cretaceous Colville groups and the upper part of the Torok are subdivisions of the post-orogenic deposits that filled the Colville geosyncline.

The Nanushuk and Colville groups are chiefly nearshore deposits (winnowed sandstones are gas or oil-bearing) included in the Colville geosyncline as the basin was filled. They intertongue northward with the Torok and subsurface shale units that were deposited offshore.

An important misfit in the depositional picture is the Nuka formation--a formation consisting of upper Paleozoic arkosic quartz and calcite sandstone.

In its type section in the west-central disturbed belt, the Nuka formation consists of a cylically repeated sequence, over a mile thick, of coarse clastic, fine clastic and carbonate, and chert members containing Mississippian fossils near the base and Permian fossils in the upper half; elsewhere, clastic rocks no more than a few hundred feet thick have been recognized.

Exposures of the Nuka have been found on the west coast, in the DeLong Mountains, and along the disturbed belt eastward to the Anaktuvuk River.

A deposit of such magnitude must have required a granite provenançe some 350 miles long and lapped by a shifting sea. Whether to look for this phantom granitic terrane beneath the Colville geosyncline to the north or to assume that it has been obscured by complexities to the south of the Brooks Range is yet to be determined, nor is it agreed whether the Nuka formation is structurally the highest or structurally the lowest of the Cretaceous units.

Cretaceous rocks underlie most of the North Slope, and the Late Cretaceous sequence is believed to contain tremendous coal reserves. The following discussion of the coal deposits in northern Alaska (Barnes, 1967, p. B16-B18) is included to indicate the extent of nonmarine deposits which may have a potential for sedimentary uranium:

The principal coal-bearing districts of northern Alaska lie north of the Brooks Range and west of the Itkillik and lower Colville Rivers. The southern part of this area consists of a broad upland dissected into rolling hills, north of which the nearly flat Arctic Coastal Plain extends to the Arctic Ocean. Coal-bearing Cretaceous rocks are known or inferred to underlie 58,000 square miles of this area. These

rocks, consisting mainly of alternating layers of sandstone and shale, have been folded into eastward-trending anticlines and synclines. Because of differences in resistance of the rocks to erosion, the folds are expressed topographically by the general east-west alinement of the ridges and valleys. Near the mountains the folding and faulting has been more intense and in places the strata stand nearly vertical, but in the northern foothills, which includes the southernmost coal-bearing rocks, deformation has been only moderate, and farther north under the Coastal Plain the beds are nearly horizontal.

East of the Itkillik and lower Colville Rivers a few scattered coal beds have been reported in Cretaceous rocks, and several possibly extensive areas are underlain by lignite-bearing Tertiary rocks. Far to the west, along the coast south of Cape Lisburne, bituminous coal is exposed in several places in strongly folded and faulted Mississippian rocks. Since little is known of the nature and extent of the coal deposits in these two regions no resource estimates were made.

The following descriptions of the principal coal districts are based on several published reports on different parts of northern Alaska (Chapman and Sable, 1960; Chapman and others, 1964; Detterman and others, 1963; Keller and others, 1961). In computing coal resources in northern Alaska, it was assumed that the known great areal extent of the several coal-bearing units, plus the almost universal presence of potentially valuable coal beds in such units, justified the use, in determining the extent of individual coal beds, of broader limits than were used in other parts of Alaska, where the coal-bearing units are known to be of much smaller extent and the individual beds are characteristically lenticular. Accordingly, in computing tonnages, indicated coal was assumed to extend 1 mile rather than half a mile, and inferred coal 6 miles, from outcrops or drill holes except where shown by geologic evidence to terminate at a shorter distance.

<u>Corwin Bluff-Cape Beaufort district.</u>--At least 20 beds of bituminous coal ranging from 2-1/2 to 9 feet in thickness, as well as many thinner beds, are exposed in beach bluffs from the vicinity of Corwin Bluff, about 30 miles east of Cape Lisburne, to Cape Beaufort. These beds dip moderately to steeply southwestward from the eastward-trending coast, and one inland outcrop shows that the coal-bearing rocks extend at least 10 miles along the strike.

<u>Kukpowruk River district.</u>--Coal-bearing rocks are exposed at intervals along the lower 25 miles of the Kukpowruk River, where they lie in a series of eastward-trending folds which dip 12^{o} -55^{o}. Forty coal beds 1-1/2-13 feet thick were measured along the river; some of the beds may be repeated by folding. Coal-bearing rocks also underlie a small area 70 miles above the mouth of the river and include at least one 3-foot bed of coal. Analyses show all this coal to be of bituminous rank. Because these beds are exposed only in

the river valley, their lateral extent is unknown, but geologic evidence suggests that large areas on both sides of the river may be underlain by coal beds of minable thickness.

Kokolik-Utukok Rivers district.--Coal beds ranging from 2 to 6 feet in thickness are exposed at several points along the Kokolik River near the northern edge of the foothills belt. The beds have been slightly to moderately folded, and the coal is probably all of bituminous rank. Coal is exposed at intervals along the Utukok River between points 25 and 80 miles above its mouth in beds ranging from a few inches to nearly 12 feet in thickness. These beds also have been slightly to moderately folded, but the coal appears to decrease in rank northward, from bituminous in the foothills to subbituminous on the Coastal Plain.

Kuk-Kugrua Rivers district.--Beds of subbituminous coal, ranging from 3 to 14-1/2 feet in thickness, crop out at several points along the Kuk and Kugrua Rivers near the Arctic coast south and east of Wainwright. These beds are all nearly horizontal, and some of them reportedly have been traced for several miles along the east shore of the Kuk estuary (Smith and Mertie, 1930, p. 308), so they may closely underlie many square miles of the surrounding Coastal Plain.

Farther inland a test well near the Kaolak River, a principal head water tributary of the Kuk, disclosed a thick coal-bearing section, including 36 coal beds ranging from 3 to 26-feet in thickness, within 3,000 feet of the surface. Geophysical evidence indicates that the well is near the axis of a broad anticline with gently dipping limbs (Collins, 1958, p. 353). Although no fresh samples from this well were analyzed, the coal is probably of subbituminous rank because in northern Alaska coal-bearing rocks that are more intensely folded generally contain bituminous coal.

Meade-Ikpikpuk Rivers district.--The Mead and Ikpikpuk Rivers both head in the northern foothills belt and flow northward across the Coastal Plain to the Arctic Ocean. Coal of probable bituminous rank is exposed at several localities near the head of the Meade River, in beds ranging from 2 to 6 feet in thickness. Farther downstream subbituminous coal, in beds mostly less than 5 feet thick, crops out at several localities between points 25 and 100 miles from the mouth of the river. At one point a small strip mine has been operated to supply fuel for the village of Barrow. A test well a few miles west of the river near the southern edge of the Coastal Plain cuts a coal-bearing section that includes 21 coal beds 4-30 feet thick, within 2,000 feet of the surface. This coal also lies in a broad anticline and is considered to be of subbituminous rank.

Subbituminous coal is exposed at several places along the Ikpikpuk River on the Coastal Plain, but all the known beds are too thin to be of value. On the Kigalik River, a headwater tributary of the Ikpikpuk in the foothills belt, several beds of subbituminous coal 2-1/2-5 feet thick are

exposed, and two beds of comparable thickness were found in a test well just east of the upper Ikpikpuk River.

Colville River district.--In the Colville River district, including the basin of the Colville River and its many large tributaries, coal is widely distributed both in the foothills and on the Coastal Plain. Subbituminous coal occurs in the eastern part of the district, principally in the Prince Creek Formation of Late Cretaceous age, in beds that are mostly less than 5 feet thick but include a few that are 10 feet thick. Bituminous coal crops out at many points along the northeast-trending segment of the Colville River and its southern tributaries, in the Chandler Formation of Cretaceous age. The beds range in thickness from a few inches to 8 feet, but many of them are less than 3 feet thick. The subbituminous coals south of the Colville River generally occur in broad synclinal basins with low dips; those west of the north-flowing segment of the Colville River are nearly horizontal. The bituminous coal is restricted to the moderately folded rocks of the foothills belt.

In a general description of the Late Cretaceous lithology, Detterman (1973, p. 386) points out the abundance of tuffaceous material in the sequence and the presence of coal and sandstone:

The final phase of late Mesozoic deposition was a period of abrupt marine regressions and transgressions starting in the Coniacian and continuing throughout the remainder of the Cretaceous. Massive conglomerate and sandstone units with interbeds of siltstone, shale, coal, and bentonite were deposited in a nonmarine environment that intertongues with marine sandstone, siltstone, shale, and tuff; the tuff is present both as individual beds and as a detrital constituent of the other rocks. The Late Cretaceous nonmarine rocks are included in the Prince Creek Formation, and the marine strata are assigned to the Schrader Bluff Formation; the formations are further divided into members and tongues. In northeastern Alaska, equivalent strata are included with the upper part of the Ignke Formation.

Several thousand feet of Late Cretaceous conglomerate, sandstone, mudstone, shale, coal, and tuff is preserved south of the Brooks Range. These rocks are entirely nonmarine; no evidence of a marine transgression into central Alaska in Late Cretaceous time has been found. Intrusive and extrusive igneous activity accompanied the filling of the Koyukuk basin, and volcanic detritus is locally a major part of the sedimentary pile (Patton and Miller, 1966, 1968; Patton et al., 1968). This volcanic activity probably supplied the ash and bentonite found in the rocks north of the range.

The source of the molasselike Late Cretaceous detritus was primarily the Brooks Range, although some was undoubtedly supplied by folded early Mesozoic strata in the modern foothill belt. Rocks exposed along the Meade arch may have supplied some of the detritus for the nonmarine strata along the northwest coast.

Faunal remains are locally abundant in northern Alaska and exhibit the greatest diversity in the Seabee Formation at the base of the Colville Group. Ammonities and pelecypods present in this major marine transgressive sequence include Borissjakoceras, Scaphites, Inoceramus labiatus, and I, cuvieri. A few pelecypods occur in nearshore deposits of late Santonian and early Campanian age; the main elements of this assemblage are Inoceramus steenstrupi and I. patootenis (Jones and Gryc, 1960).

Late Cretaceous rocks are poorly consolidated as compared to Early Cretaceous and other Mesozoic strata. The subgraywacke sandstones are moderately well sorted and considerably cleaner than the older beds, although most have a tuffaceous matrix. The contact between Late Cretaceous and early Tertiary rocks cannot be located with any degree of certainty in Arctic Alaska. The beds are for the most part structurally conformable across the contact, although a hiatus of considerable magnitude may be represented. No significant change has been noted in clastic constituents, degree of induration, or coloration between Late Cretaceous and Tertiary strata.

Little is known about the Tertiary rocks which lie in the eastern part of the Arctic Coastal Plain. The rocks are exposed very rarely in low bluffs along the Arctic Ocean and along some major streams, and have an approximate thickness of 7,000 feet of silt and clay, with occasional pebbles, coal seams, and bentonite beds at Marsh Anticline--69° 45' latitude and 145° 00' longitude (Morris, 1957).

Along the southern margin of the Coastal Plain the lower Sagavanirktog Formation is nonmarine silt, sand and conglomerate with pebbles of older rocks including Colville Group tuff. At Prudhoe Bay the Lower Tertiary section of the Sagavanirktok grades down into the Colville Group, as indicated by sparse megafossil control, while the upper section is considered to be marine silts and sands of Miocene age.

The Sagavanirktok ranges in age from Early Tertiary to Miocene or Pliocene, and is generally overlain unconformably by Pleistocene(?) gravels.

Lithologic descriptions of the Tertiary are quoted from Keller, Morris, and Detterman (1961, p. 207-209):

The Sagavanirktok formation consists of nonmarine to beach-type sediments consisting of poorly consolidated conglomerate, sandstone, and siltstone with interbeds of shale and coal. The conglomerate crops out as lenticular masses, grades laterally into crossbedded massive coarse-grained sandstone, and contains rounded pebbles and cobbles of white quartz, green and black chert, quartzite, igneous rock, and silicified tuff lithologically similar to that present in the lower part of the upper member of the Ignek formation. The sandstone ranges from light gray to buff, yellow brown, pink, and red, and locally is moderately porous and permeable. The siltstone is medium to light gray, slightly calcareous, and friable to semi-consolidated. The coal is thin bedded and of low rank; it

has a dull to waxy luster. Except for one questionable pelecypod impression, no fauna was found in the formation. The siltstone and shale interbedded with the coal do contain a flora, but no collections were made. The rock unit has been mapped as the Sagavanirktok formation, partly because of its lithologic similarity to the rock unit described by Gryc, Patton, and Payne (1951, p. 167) and partly because it can be traced, although somewhat discontinuously, to the Sagavanirktok River where the Sagavanirktok formation has been noted.

Measured sections.--Two sections of the Sagavanirktok formation were measured in the mapped area and these are shown on plate 23. The locations of the sections are shown on plate 21.

Section 17 was measured in the area just west of the Kavik River where an incomplete sequence about 1,600 feet thick is preserved in a broad syncline. The basal conglomerate of the Sagavanirktok formation overlies the Ignek formation at this locality with no apparent angularity, and the upper beds of the formation have been eroded. The massive sandstone and conglomerate beds form resistant ledges which are separated by tundra-covered lowlands. The nature of the rocks underlying the tundra has, where possible, been inferred from the character of the material brought to the surface by frost heaving.

Sagavanirktok formation, section 17

	Feet
Coarse-grained poorly consolidated light-gray sandstone with a few quartz and chert pebble to granule lenses; sandstone weathers light yellowish brown; massive crossbeds as much as 4 ft thick; few plant remains and bituminous(?) material - - - - - - - - -	50
Mostly tundra covered; small amount of light-brown sandy shale- -	120
Clean poorly consolidated light-gray coarse sandstone and lenses of conglomeratic sandstone; conglomerate constituents are well-rounded white quartz, olive, gray, and black chert, silicified tuff, and a few pebbles of quartzite; massive crossbedding in upper part of unit; plant remains and thin beds of low-grade coal in lower part- - - - - - - - - - -	40
Mostly tundra covered; some fine-grained sandstone and gray shale -	290
Poorly consolidated buff to light-gray sandstone and conglomerate similar to that described above - - -	50
Tundra covered- -	70
Poorly consolidated conglomerate and coarse light-gray to buff sandstone; sand grains and subround quartz and chert; the pebbles in the conglomerate are well rounded and comprise white quartz and minor chert and tuff -	60
Mostly tundra covered; some sandy shale - - - - - - - - -	230

	Feet
Friable coarse-grained light-gray massive sandstone, and conglomerate containing rounded pebbles and cobbles of white quartz, chert, and tuff; conglomerate cemented with limonite; one poorly preserved pelecypod impression on a sandstone bedding plane; sandstone in upper part of unit has a porosity of 14.6 percent and a permeability of 14 millidarcys -	70
Mostly tundra covered; some fine-grained light-gray sandstone with a porosity of 17.75 percent and a permeability of 10 millidarcys- - - - - - - - - - -	580
Conglomerate and sandstone as described above; sandstone massive, crossbedded, almost impermeable with a porosity of 5.53 percent - - - - - - - - - - -	40
Total measured thickness of Sagavanirktok formation- -	1,600

Ignek formation, upper member.

Section 10 is a composite and includes the exposures in the cutbanks along the east side of Fin Creek and the outcrops of the formation on the south flank of the Shaviovik anticline between Fin Creek and the Shaviovik River. The rocks dip as much as 37° N. in the exposures along the creek and dip from 8° to 24° S. on the south flank of the anticline. The contract of the formation with the underlying Ignek formation is not exposed at this locality, but just north of the measured section in the breach of the anticline along Juniper Creek the rocks of the Ignek formation dip more steeply than do the rocks of the over-lying Sagavanirktok formation, and a structural unconformity is indicated between the two rock units. The upper beds of the younger formation have been eroded at this locality.

Sagavanirktok formation, section 10

	Feet
Fine- to medium-grained yellowish-brown-weathering friable sandstone -	40
Mostly tundra covered; some ferruginous shale- - - - - -	200
Medium-grained yellowish-brown-weathering friable sandstone -	25
Tundra covered -	45
Friable light yellowish-gray clean sandstone with interbeds and lenses of sandy conglomerate; conglomerate constituents are rounded cobbles and boulders from 6 in. to 1 ft in diameter of quartzite, white quartz, tuff, and fine-grained igneous rock and limestone of Mississippian age- - - - - - - - - - -	200
Fine- to medium-grained light-gray friable clean sandstone -	60
Mostly tundra covered; some fine-grained yellowish-gray sandstone and sandy shale- - - - - - - - - - -	100

	Feet
Low-rank coal with blocky fracture and dull to waxy luster; coal seams as much as 2 ft thick; interbeds of light-gray clay shale and siltstone; plant remains- -	*20*
Sandy light-gray shale and dark shale containing carbonaceous fragments and plant remains- - - - - - - - -	*100*
Yellowish-brown medium-grained friable crossbedded sandstone; minor lenses of conglomerate containing rounded pebbles of chert, tuff, and white- -	*70*
Massive beds of sandstone and lenses and beds of conglomerate as much as 15 ft thick; conglomerate contains pebbles and cobbles of rounded white quartz, chert, tuff, limestone (Lisburne) and quartzite (Sadlerochit?) in a limonite matrix; sandstone friable, light-gray to yellowish-brown, crossbedded; plant remains and coaly material along bedding planes; salt-and-pepper sandstone with a porosity of 17.1 percent and a permeability of 420 millidarcys; 5-ft bed of light-pink medium-grained sandstone near top of unit - - - - - - - - - -	*410*
Tundra covered- -	*120*
Yellowish-brown-weathering coarse-grained sandstone - - -	*75*
Medium-gray thin-bedded shale - - - - - - - - - - - - - - - - - -	*40*
Interbedded friable sandstone and conglomerate- - - - - -	*190*
Tundra covered; salt-and-pepper sandstone at base and sandy medium-gray shale- - - - - - - - - - - - - - - - - -	*270*
Contact (arbitrarily placed at base of sandstone).	
Total measured thickness of Sagavanirktok formation -	*2,045*
Ignek formation (upper member).	

The Sagavanirktok formation overlies the Colville group with local erosional unconformity. In the White Hills area, it is composed of conglomerate, silty sandstone, and siltstone. Red, brown, and yellow beds alternate with nearly white strata (Burnside, 1959, p. 135). The significance of the alternation that may have accompanied leaching and redeposition of uranium is considered a possibility.

Intrusive rocks of Cretaceous age, consisting mostly of quartz monzonite to granite, are exposed in a batholith and as stocks in the Romanzof Mountains in the east-central part of the Mount Michelson quadrangle (Sable, 1965a, b; Reiser and others, 1971). Minor amounts of metallic sulfides and oxides are present in the granite and the Neruokpuk Formation rocks. Analyses of stream-sediment samples suggest tin and beryllium potential.

Radioactivity of gneissic granite in the Mount Michelson area (White, 1952, p. 1-7) was above average for granitic rocks, and minerals commonly associated with uranium are present in the intrusives. A summary of White's investigation follows:

> *Radiometric examination of 13 samples collected in the Mount Michelson area, northeastern Alaska, in 1948, shows that four samples of gneissic granite contain an average of 0.007 percent*

equivalent uranium. The heavy-mineral fractions from three of these four samples contain an average 0.052 percent equivalent uranium and 0.03 percent uranium. The heavy-mineral fractions of panned concentrates from gravels of streams draining relatively large areas of granitic rock, contain an average of 0.028 percent equivalent uranium, whereas similar heavy fractions of panned concentrates from streams that drain areas other than those largely underlain by granitic rock contain an average of only 0.005 percent equivalent uranium.

Mineralogic study of all heavy-mineral fractions having more than 0.01 percent equivalent uranium indicates that the radioactive material apparently is confined to biotite, which in one sample contains 1.19 percent uranium. Fluorite, hematite, zircon, sphene, galena, and molybdenite, commonly associated elsewhere with uranium, apparently are disseminated in the granite with the biotite.

The presence of uranium in the biotite of the granite and, of other minerals associated with uranium elsewhere, suggests that this area should be considered in relation to others in Alaska as a possible locality to search for high-grade uranium deposits.

A great amount of geologic information on the North Slope has been generated during the past few years as a result of 1) the discovery of oil at Prudhoe Bay, 2) studies of the Naval Petroleum Reserve No. 4, and 3) the drilling of numerous wells. However, much of the data has not been published and it is still difficult to speculate on the uranium potential of the region. Radioactivity logs are frequently not run, especially through the shallower depths. Carbonaceous and tuffaceous beds and nonmarine sandstone of Tertiary and Late Cretaceous ages are known to be widely distributed, but no anomalous radioactivity has thus far been reported. However, uranium has not been specifically sought in on the North Slope.

The North Slope is tundra-covered and exploration for uranium in the Late Cretaceous sediments would need to rely on drilling or examination of outcrops in the northern foothills of the Brooks Range. Perhaps the wells that have been drilled for petroleum could be relogged, and some information could be obtained by examination of logs already available. The Tertiary rocks are exposed at scattered locations in the eastern part, and some direct studies of their uranium potential could be made. The granitic rocks in the Mount Michelson area of the Romanzof Mountains seem to have a potential for vein-type deposits and also could be a source for uranium in sediments.

THE CANTWELL FORMATION

The Cantwell Formation is a Paleocene nonmarine unit in the central part of the Alaska Range that may have a potential for sedimentary uranium deposits. First named the Cantwell Conglomerate (Eldridge, 1900, p. 16), the formation underlies approximately 1,500 square miles and reaches a maximum thickness of 10,000 feet; the thickness generally ranges from 2,000 to 5,000 feet. The original upper surface has been eroded.

The Cantwell Formation occupies a large synclorium that trends eastwest along the trend of the Alaska Range (fig. 71). A considerable part lies within the

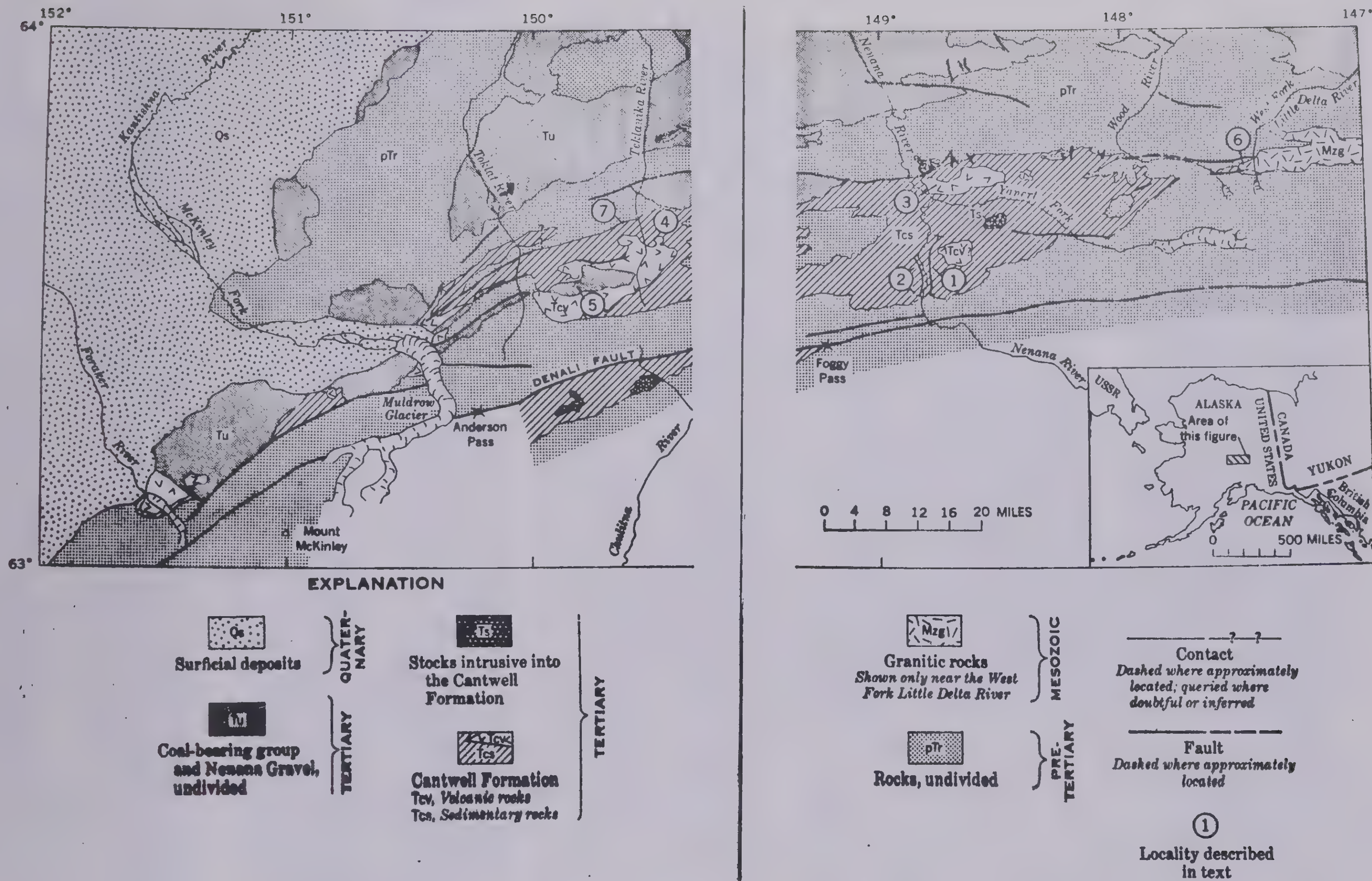


Figure 71. Geologic sketch map of the central Alaska Range showing distribution of the Cantwell formation, related formations, and localities referred to in text. Geology modified from Reed (1961, pl. 1), Wahrhaftig (1958, pl. 1), and Capps (1912, pl. 2). (Source: Wolfe and Wahrhaftig, 1970, p. A42-A43.)

boundaries of Mount McKinley National Park. The type locality is considered to be the east wall of the Nenana River canyon, from the mouth of Slime Creek northward for 7 or 8 miles in the Healy C-4 quadrangle.

The lithologic description of the Cantwell Formation is taken from Wolfe and Wahrhaftig (1970, p. A44-A45):

> *The Cantwell Formation consists predominantly of interbedded conglomerate, sandstone, argillite, shale, and coal but also contains volcanic rocks, especially near its top. The Cantwell is intruded by an abundance of sills and dikes ranging in composition from diabase to rhyolite and by monzonite stocks as much as 3 to 4 miles across.*
>
> *At two localities the Cantwell Formation is clearly younger than large intrusive bodies. (1) At the pass between the headwaters of the Wood River and the West Fork Little Delta River, it rests unconformably on granodiorite and quartz monzonite at the west end of a large batholith which was traced eastward by Capps (1912, pl. 2) as far as Delta Creek, a distance of 30 miles; the granodiorite beneath the contact has been weathered to grus for a thickness of 20 feet. (2) On the east side of the Muldrow Glacier, dikes believed to be feeders to the volcanic rocks of the Cantwell Formation cut the intrusive body underlying Mount Eielson (Reed, 1933).*
>
> *The Cantwell Formation is generally moderately well consolidated and is locally very well indurated. Some beds in the formation are extremely well sorted pebble conglomerate consisting of quartz, chert, quartzite, and argillite pebbles with little or no matrix. Few of the pebbles are less than half, or more than twice, the median size. The pebbles are indented and moulded against each other, possibly as a result of solution and redeposition of silica under tectonic pressure; the conglomerate therefore has negligible porosity.*
>
> *Coal in the Cantwell Formation is generally of bituminous rank, even where beds are tightly folded and the conglomerate compressed, as in the vicinity of mafic dikes.*
>
> *Dark flows and rhyolite tuffs occupy an open syncline centered on Mount Fellows. A belt of predominantly silicic volcanic rocks is exposed at the top of the formation from Double Mountain (fig. 4, loc. 4) westward to the Muldrow Glacier. These silicic volcanic rocks give Polychrome Pass its color variety. In both the Mount Fellows and Polychrome Pass areas, the volcanic rocks are at the top of the section, yet only 1,000 to 3,000 feet of sedimentary rocks lies between the volcanic rocks and the base of the formation. The volcanic rocks at Mount Fellows and Polychrome Pass may be equivalent to lower parts of the Cantwell Formation at other places, or they may have erupted in areas where highlands in the pre-Cantwell topography rose a few thousand feet above the base of the formation elsewhere.*
>
> *The lithology of the clasts in the Cantwell Formation varies from place to place, suggesting that the formation was derived from at least three different sources. In the type area along the Nenana River, the sandstone and conglomerate are predominantly dark gray and consist largely of argillite, chert, quartzite, and quartz grains and pebbles. The source of this dark-gray facies was probably south of*

the Alaska Range, possibly in the Mesozoic rocks in the Talkeetna Mountains or the southern Alaska Range. Along the north edge of the area of outcrop of the Cantwell east of the Nenana River this facies interfingers with light-brown to white sandstone and conglomerate consisting largely of schist fragments derived from the Birch Creek and Totatlanika Schists immediately to the north. From the vicinity of Polychrome Pass westward, the dark-colored Cantwell is replaced by light-brown conglomerate and sandstone that consist largely of clasts of gray limestone in a light-brown matrix of unknown composition and origin. The westward limit of this light-colored limestone-bearing facies is unknown. Its source could have been the area of Devonian limestone near the crest of the range (and on the north side of the Denali fault) immediately south of its area of outcrop.

The limestone-bearing facies has not been mapped in the Cantwell Formation south of the Denali fault, as this body has not been visited since Capps' reconnaissance in 1930. A study of this facies and its correlation with facies north of the fault might give information on the lateral displacement of the fault since Paleocene time.

Additional descriptions of the Cantwell Formation appear in publications by Wahrhaftig and Black (1958, p. 8-9), Gates and Gryc (1963, p. 272), and Wahrhaftig (1958, p. 79-80). A more detailed stratigraphic study of the formation is currently being conducted by John Decker of the University of Alaska as a thesis topic, and more information on this interesting unit will be available on its completion.

The only investigation for radioactivity in the Cantwell Formation known to this writer consisted of some spot checking along the highway (Eakins, 1969, p. 16). No anomalous radioactivity was observed.

BRISTOL BAY TERTIARY PROVINCE

Bristol Bay is a broad gulf between the Alaska Peninsula and the mainland on southwestern Alaska. It is about 175 miles wide at its mouth, where it joins the Bering Sea. Adjacent lowlands on the upper part of the Alaska Peninsula and along the lower Nushagak and Kvichak Rivers are part of the province considered here (fig. 72). The province is also called the Nushagak Basin (Payne, 1955).

Bristol Bay, a potential petroleum province, has received considerable study by oil companies and is covered by seismic surveys. The onshore lowlands are covered by Quaternary deposits and a myriad of lakes. It is underlain by isolated masses of permafrost. A number of villages are located along the coast and the rivers, and the region is accessible by aircraft or boat. The weather is often unfavorable for flying for several days at a time, however, because of fog and strong winds.

Highly deformed Cretaceous and older rocks are overlain unconformably by several thousand feet of interbedded marine and nonmarine Tertiary sediments containing sandstone and coal beds of possible interest to uranium explorationists. Tertiary deposition began in Eocene time.

A granite batholith on the northern part of the Alaska Peninsula and granitic stocks and volcanic materials in the Nushagak and Kvichak River regions may have

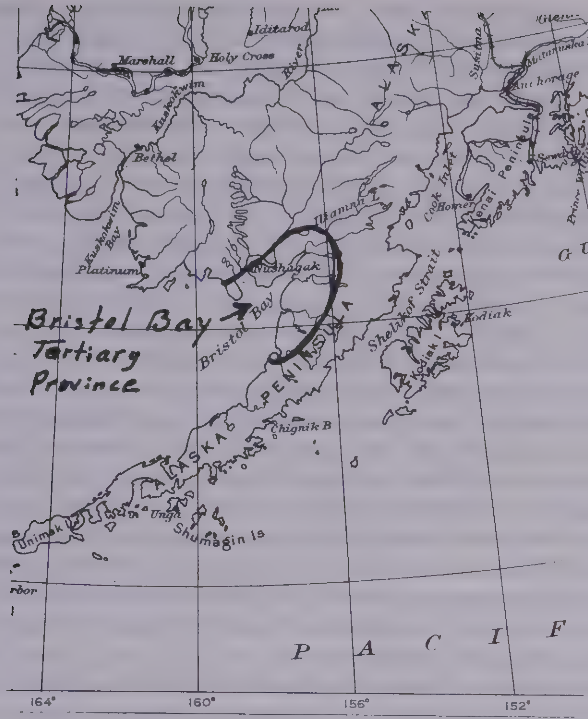


Figure 72. Index map of the Bristol Bay Tertiary province. (Source: U.S. Geol. Survey Map C.)

been sources for uranium in the sediments. The following discussion of the Bristol Bay Tertiary province is from Gates, Grantz, and Patton (1968, p. 28-29):

> *A broad topographic apron underlain by thick glacial and alluvial deposits of Quaternary age slopes north to Bristol Bay from the mountains which form the backbone of the Alaska Peninsula. This apron is part of the Nushagak lowland, which also includes the swampy flats around the Nushagak and Kvichak Bays. Sedimentary rocks of the Bristol Bay Tertiary province (Fig. 5) underlie much or most of the topographic apron on the north side of the Alaska Peninsula from near Becharof Lake to Port Moller and extend for an unknown distance northward and westward beneath Bristol Bay. Lava and volcanic clastic detritus from the volcanoes of the modern Aleutian arc have contributed to the Quaternary fill, and probably to the upper Tertiary sedimentary section as well. The extent of the area underlain by a significant thickness of Tertiary rocks is poorly known because of the extensive surficial deposits and the paucity of published geological and geophysical data on this region. However, this area is probably no less than 250 mi long, may be more than 20 mi wide, and probably exceeds 7,500 sq mi in area. The published information on the geology of the area is mainly from reconnaissance surveys at the margins of the Bristol Bay-Nushagak lowland*

by Atwood (1911), Knappen (1929), and Mertie (1938). These are supplemented by data of MacNeil and others (1961), by stratigraphic information obtained in test wells drilled for petroleum near Becharof Lake (140 mi west of Kodiak), and by the results of aeromagnetic surveys (Andreasen and others, 1963a, 1963b; Henderson and others, 1963). Unpublished paleontologic data were contributed by F.S. MacNeil.

The Bristol Bay-Nushagak lowland is bordered on the north and northwest by Cretaceous shale and graywacke containing scattered intrusions of granitic rocks and common quartz veins. Dips in these rocks are steep and faults are prevalent. General lack of porosity and structural complexity make the rocks unfavorable for petroleum accumulation. However, the rocks may extend beneath the surficial deposits of the lowland and may be more favorable for petroleum there. Plutonic rocks of Jurassic age are exposed northeast of the lowland, and aeromagnetic data suggest that these and perhaps other magnetic rocks extend beneath the northeastern part of the lowland at shallow depth. Southwest of Becharof Lake the lowland is bounded on the southeast by petroliferous rocks of the Alaska Peninsula-Cook Inlet Mesozoic province and by marginal outcrops of sedimentary and volcanic rocks of the Bristol Bay Tertiary province.

Tertiary sedimentary rocks of the Bristol Bay Tertiary province penetrated in two test wells near Becharof Lake are intermingled marine and nonmarine clastics. They consist of sandstone, siltstone, shale, conglomerate, and coal from the surface to depths of about 11,000 ft in the more eastern well and about 8,800 ft in the more western well. In the deeper well the lowest beds consist of conglomerate and sandstone overlying andesite. A few marine mollusk shells, foraminifers typical of shallow and brackish sea water, and abundant coal and carbonaceous material are scattered through the section, and much tuffaceous material was found in the lower half of the wells. The section may range in age from Paleocene or Eocene to Miocene. Basement in both wells consists of igneous and metamorphic rocks. Marginal outcrops of the Tertiary province in the Aniakchak district, between Becharof Lake and Port Moller, were considered by Knappen (1929) to be nonmarine. He reported that the lowest unit consists of black fissile shale with fine to coarse sandstone and a little conglomerate. It is 0-2,000 ft thick and is overlain by 2,000-5,000 ft of black shale with interbeds of bentonitic clay and volcanic sediments. This composite unit is overlain by andesitic tuffs and agglomerates with a few lava flows. These units were considered by Knappen (1929) to be Eocene, but are thought by MacNeil and others (1961) to be Oligocene. Above them lies the Meshik Formation of Oligocene or Miocene age --2,000 to possibly 4,000 ft of andesitic conglomerate, ash, bentonitic clay, and a few andesite flows. Sedimentary rocks containing upper(?) Miocene marine fossils also are found in the area, overlain by volcanic rocks of latest Cenozoic age.

The Tertiary beds near Port Moller, on the north side of the Alaska Peninsula, and in the Unga Island area, on the

south side of the Alaska Peninsula, include fossiliferous clastic marine sedimentary rocks, nonmarine coal-bearing sedimentary rocks, and some volcanic rocks. These rocks constitute a section of considerable thickness and represent each epoch of the Tertiary from at least the Eocene to the Pliocene. The oldest paleontologically dated Tertiary beds are marine and are of middle and late Eocene age. They are succeeded locally by lower Oligocene(?) volcanic rocks and by widespread fossiliferous marine and nonmarine beds, pre-dominantly of middle Oligocene age. Above these are middle Miocene to lower Pliocene fossiliferous marine sedimentary rocks and Pliocene to Recent volcanic rocks.

Exposures in the Bristol Bay Tertiary province are not abundant, and the thickness and especially the extent of its rocks must be determined by geophysical methods or drilling. Aeromagnetic data suggest that the section in the province is not sufficiently thick to be promising for petroleum north of Becharof Lake and King Salmon River, and reconnaissance gravity data by D.F. Barnes (oral communication, 1963) suggest that it may not extend beneath Bristol Bay in the area north of Ugashik Bay (110 mi south and east of Dillingham). However, aeromagnetic data suggest that this or some other body of sedimentary rock extends along the north-trending portion of the lower course of Nushagak River upstream of Dillingham, and reconnaissance gravity and geologic data indicate that the Bristol Bay Tertiary province extends beneath Bristol Bay in the area southwest of Ugashik Bay. The ultimate petroleum potential of the province may depend on the presently unknown offshore extent of these rocks in the area southwest of Ugashik Bay. The potential of the segment in the Unga Island area will depend on the thickness and extent of the Tertiary section in the area between the axis of the Alaska Peninsula and the outer Shumagin Islands, which are composed of igneous and metamorphic rocks. The Tertiary sedimentary rocks of the Unga Island segment may continue west, beneath the volcanic rocks of the westernmost Alaska Peninsula, and could extend beneath the continental shelf around the outer Shumagin Islands. If either extension exists, the Unga Island segment might be of significant size.

The petroleum potential of the Bristol Bay Tertiary province lies in the presence, beneath a large area, of a fairly thick sequence of interbedded and intertonguing marine and coal-bearing nonmarine rocks of Tertiary age. By anology with the Cook Inlet subprovince these Tertiary rocks are likely to contain porous and permeable beds which could serve as petroleum reservoirs. They contain coal and carbonaceous beds which might have generated large quantities of methane gas, and have a possible source for petroleum in their marine beds. The latter may be relatively more abundant on the southwest, toward the tip of the Alaska Peninsula. In the area southwest of Ugashik Lakes, where the Tertiary rocks overlie petroliferous Mesozoic rocks of the Alaska Peninsula subprovince, the Tertiary rocks may contain oil of Mesozoic origin. Although indications of oil have not been

reported from the Bristol Bay Tertiary province, and although three test wells (of which at least two penetrated the entire Tertiary section) were dry, the possible presence of petroleum source and reservoir rocks within the province, and its fairly large area, suggest that the province could contain commercial deposits of petroleum.

There have been no investigations for radioactivity reported in the Bristol Bay region. The lowlands would be difficult to prospect because of the lack of outcrops and the cover of Quaternary deposits. The two test wells drilled near Becharof Lake may provide some useful information. Detailed studies and sampling in the areas marginal to the lowlands might suggest favorable locations to drill for sedimentary uranium.

HOLITNA AND MINCHUMINA BASINS

Most of the known information on the Holitna and Minchumina basins has been concisely summarized by Miller, Payne, and Gryc (1959, p. 83-84):

> *The Holitna and Minchumina basins, like the Middle and Upper Tanana basins, lie north of the arcuate highland belt of the Alaska Range. A great gravel apron lies between the front of the range and the basins. The two basins are separated by a low mountainous area, and the Holitna basin is separated from the Nushagak basin by the Nushagak Hills. The Kuskokwim Mountains form the northwestern border of the basins.*
>
> *The two basins are considered together because of their similar geographic setting and because of the lack of geological information on this part of Alaska. Their total area is about 7,000 square miles, which is covered by the Lime Hills, Sleetmute, McGrath, Mt. McKinley, and Medfra quadrangles. The basin floors have an altitude of about 1,000 feet along their poorly defined southeastern borders, from which they slope gently northwestward. Drainage from the Holitna basin is by way of the Kuskokwim and its tributaries; the Holitna, Hoholitna, Stony, and Swift Rivers. Drainage of the Minchumina basin is southward by way of the Kuskokwim and its various forks and tributaries and northward by way of the Kantishna and its tributaries.*
>
> *There is no information available concerning the Cenozoic history of these basins, but because they lie in the same physiographic trend as the Middle Tanana basin the conditions described below for that basin may in part be applicable. It is likely that they contain Tertiary deposits. The Cenozoic deposits of the basins evidently lie on the complexly deformed old rocks of the Tanana geanticline (pl. 2). Seeps have not been reported.*

The general outlines of these basins are shown on fig. 73. The rather uniform slope on the northwest flank of the Alaska Range, which forms the principal portion of the Minchumina Basin, and areas of granitic rocks in the Alaska Range suggest conditions that may be favorable for sedimentary deposits. The Kantishna mining district and the highly radioactive samples collected at the Perky-Pile prospects near the western boundary of Mount McKinley National Park may indicate source areas.

The Purky-Pile prospects were discussed in the section on Tertiary Basins on the north flank of the Alaska Range.

Figure 73. Location map for Holitna and Minchumina Basins. (Source: Base, U.S. Geol. Survey Map E.)

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APPENDIX A
SYNOPSIS OF DGGS GEOLOGIC REPORT 44,
"URANIUM INVESTIGATIONS IN SOUTHEASTERN ALASKA"

This section on the uranium potential of Southeastern Alaska is a synopsis of the Alaska Division of Geological and Geophysical Surveys Geologic Report No. 44, Uranium Investigations in Southeastern Alaska, by Gilbert R. Eakins. The complete report will be published by the Division in the near future. References on Southeastern Alaska are at the end of this section rather than a part of the main list of references.

Abstract

Radioactive mineral deposits at 14 localities in Southeastern Alaska are discussed to assist in the exploration for uranium. These areas, visited during the 1970 field season, were selected because of known or reported radioactivity and (or) favorable geology. Vein deposits and nonmarine Tertiary sandstones were examined. Radiometric surveys were made on foot, and small areas were mapped to show the spatial relationship between radioactivity and certain ore deposits.

Previously unreported low radioactive anomalies were found at several localities, but none of the occurrences were indicated to be of commercial grade. Slightly radioactive sandstones were found at Port Camden and on the west side of Zarembo Island. Radioactive pegmatites at Endicott Arm and elsewhere in Southeastern Alaska do not appear to have commercial possibilities, but may serve as guides to mineralization.

The best guides for uranium exploration in Southeastern Alaska are soda-rich granite and the ores and gangue minerals frequently associated with uranium. These include minerals containing copper, silver, cobalt, and molybdenum, and hematite and fluorite. There is some indication that unusual amounts of uranium minerals are present in zones peripheral to major copper districts.

Regional Setting and Mineral Production

Southeastern Alaska is the panhandle extending from 54° 30' to 60° N. latitude. It includes a narrow strip along the mainland and more than 1,000 islands in the Alexander Archipelago. The entire region is part of the western Cordillera. The outstanding geologic features include late Mesozoic intrusive masses forming the northwest-trending Coast Range batholith and smaller subsidiary intrusives. The batholith is complex, and consists of a variety of igneous rocks of slightly different ages. The geology of the region has been complicated by tectonic activity since early Paleozoic time. Metamorphism of pre-Tertiary rocks is widespread. Major high-angle faults, with lateral displacement of many miles, have determined the locations of numerous canals and inlets.

Ore deposits in Southeastern Alaska occur near intrusive rocks. The most important ones are concentrated in four general areas (fig. 1). These include (1) the Juneau gold belt extending for approximately 125 miles along or near the coast from Berners Bay to Windham Bay, (2) the Chichagof gold district on the northwestern part of Chichagof Island, (3) the Hyder silver-lead-gold-tungsten district at the easternmost tip of Southeastern Alaska, and (4) east-central and southeastern Prince of Wales Island and the adjoining Ketchikan area, which contain mostly copper, with some gold, uranium, silver, and lead.

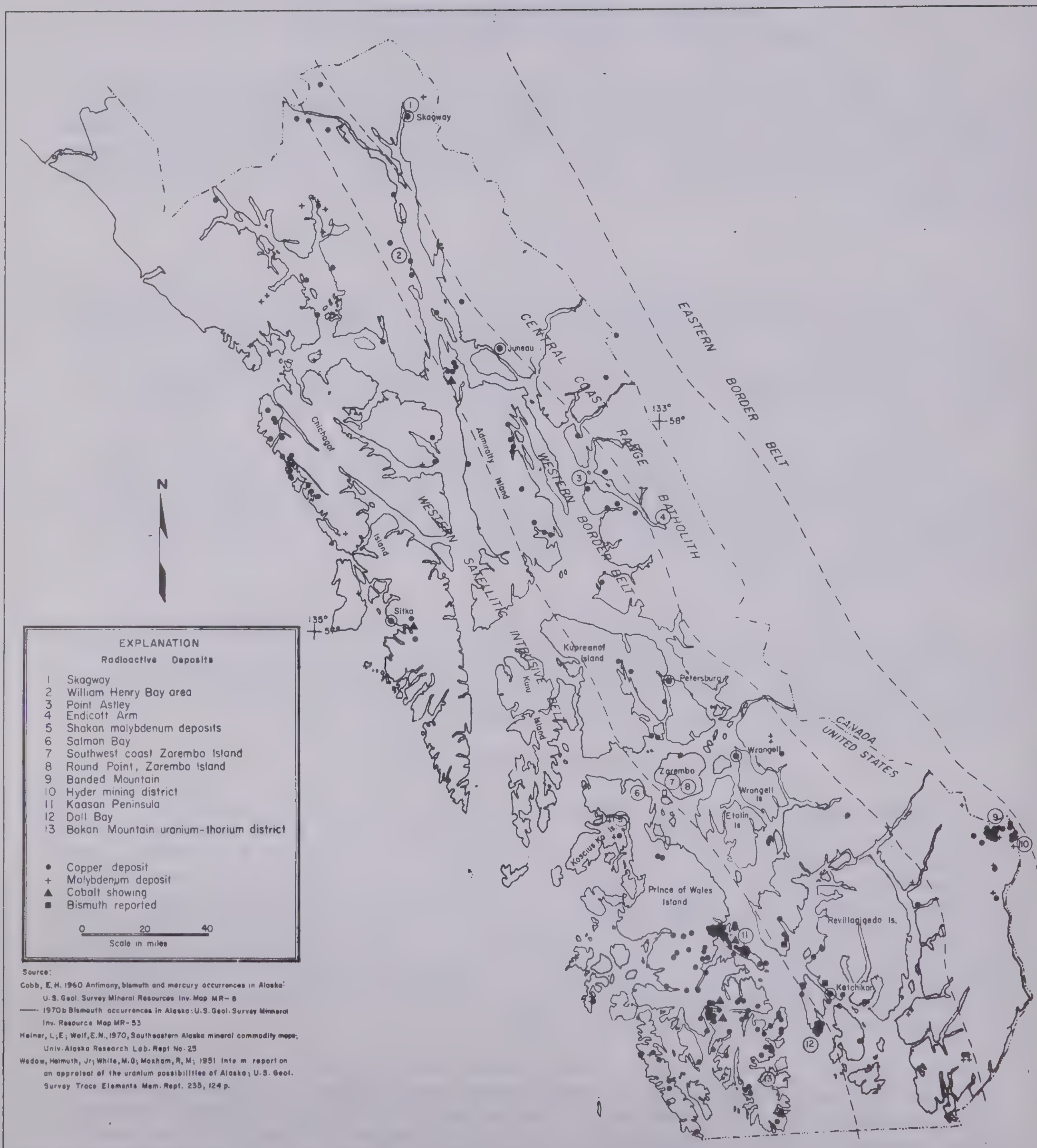

Figure 1. Distribution of certain metallic deposits and locations of known radioactive deposits in Southeastern Alaska

Between 1906 and 1956 Southeastern Alaska yielded 6.2 million ounces of gold, 3.3 million ounces of silver, 37 million pounds of copper, 48.3 million pounds of lead, 111 thousand pounds of zinc, and 14 thousand ounces of the platinum group of metals, mainly palladium (Kaufman, 1958, p. 7). Other ores mined or located contain antimony, barite, garnet, iron, molybdenum, titanium, tungsten, and recently, uranium and thorium.

Known Uranium Occurrences

Areas having significant radioactivity in Southeastern Alaska are shown on figure 2 and listed in table 1. Various modes of occurrence have been found. For example, radioactivity is associated with sulfide ore veins in the Hyder mining district, carbonate veins at Salmon Bay, pegmatite pods at Endicott Arm and Dall Bay, aplite and pegmatite dikes in the Bokan Mountain district, and granitic stocks at Bokan Mountains and William Henry Bay.

TABLE 1.-*Areas in Southeastern Alaska with Significant Radioactivity*

Location on Figure 2	Area	Geology and Radioactivity	References
1	Skagway	Country rock is quartz diorite, altered rhyolite, and andesite dikes. Specks of fluorite and iron stain present in rhyolite. One hand-picked sample from a clayey material had 1.2% U but very scarce.	Freeman, 1963, p. 30,33
2	William Henry Bay, west side of Lynn Canal	Widely scattered grains of euxenite and traces of thorianite present in an altered and brecciated granite stock which crops out over an area of one square mile. Material containing up to 1.2% eU* reported from the Lucky Six claims.	Matzko and Freeman, 1963, p. 44; present report
3	Point Astley, east side of Stephens Passage	Pyrite, sphalerite, bornite, pyrrhotite, galena, covellite, and traces of native silver in veins cutting schist. A grab sample from a copper-silver deposit assayed 0.006% eU.	Houston, Bates, Velikanje and Wedow, 1958, p. 25; Wedow and others, 1953, p. 6
4	BBH claim, Endicott Arm	Pegmatite pods in granodiorite, some pyrite and alteration. Samples collected in 1955 produced 0.04% eU. Samples collected in 1970 produced 0.004% U. A prospector reported fluorescent uranium minerals on top of ridge south of the head of Endicott Arm.	Huff, written communication, 1970; Williams, 1955a; present report
5	Shakan—molybdenum deposit, Kosciusko Island	Molybdenite, pyrite, pyrrhotite, chalcopyrite, sphalerite, and iron oxide in a breccia zone near the contact of Late Jurassic or Early Cretaceous diorite with Silurian graywacke. Maximum eU found was 0.004%.	Houston, Bates, Velikanje and Wedow, 1958, p. 24; Wedow and others, 1953, p. 9, 10
6	Salmon Bay, Prince of Wales Island	Radioactive carbonate veins cut Paleozoic graywacke and volcanics. Up to 0.13% eU, due mostly to thorium.	Bates and Wedow, 1953, p. 1, 8; Glover, 1951; Houston, 1952; Houston, Bates Velikanje and Wedow, 1958, p. 6—23; Wedow and others, 1953, p. 6, 9, 10; White and others, 1952, p. 13, 14, 16; present report

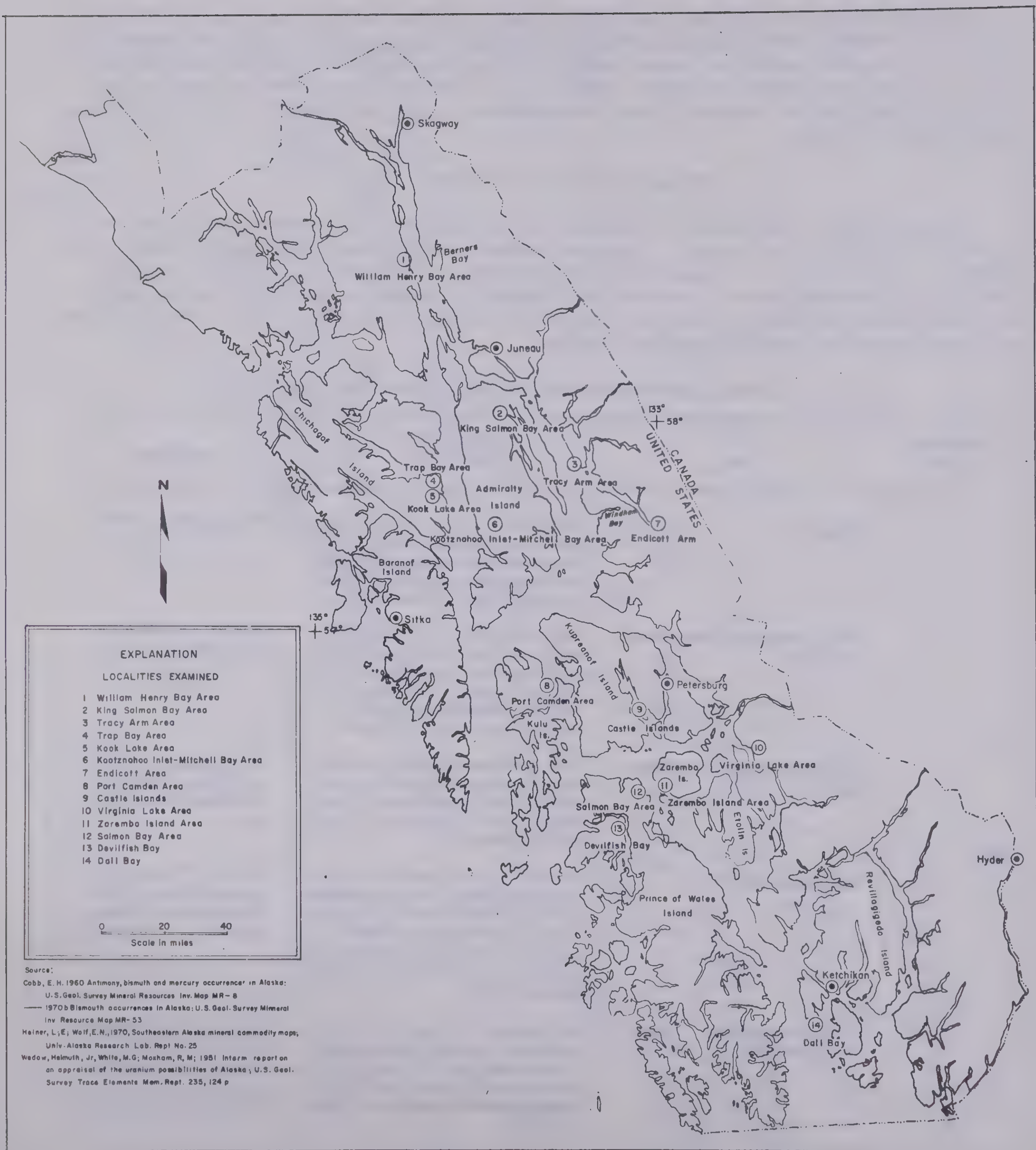

Figure 2. Localities examined for radioactivity in 1970, Southeastern Alaska

TABLE 1.-*Areas in Southeastern Alaska with Significant Radioactivity* -Continued

Location on Figure 2	Area	Geology and Radioactivity	References
7	Zarembo Island, southwest coast	Fluorite veinlets with pyrite cutting volcanic rocks. Maximum eU in felsic volcanics was 0.005%.	White and others, 1952, p. 16; present report
8	Round Point, Zarembo Island	Mesozoic granite intruded into graywacke. Thin epidote veinlets. Radioactivity in granite of 0.004% eU probably due to accessory minerals.	Houston, Bates, Velikanje and Wedow, 1958, p. 24; Wedow and others, 1953, p. 10
9	Banded Mountain, Hyder District	A radioactive sample from a copper-molybdenum prospect assayed 0.03% U.	Samples received from J. W. Huff, 1970
10	Hyder District	Silver, gold, lead, zinc, molybdenum, and tin in veins in granodiorite, greenstone, and metasediments. Small amount of U associated with hematite and the ores. A sample from the Mountain View mine assayed 0.045% eU, and lesser showings were found at other locations. An unverified assay of 0.7% eU was reported for a sample from the Mountain View property.	Fowler, 1949; Houston, Bates, Velikanje and Wedow, 1958, p. 25—29; Wedow and others, 1951, p. 54, 55; West and Benson, 1955, p. 27—45; Williams, 1952a
11	Kasaan Peninsula, east coast of Prince of Wales Island	Area has been a small copper producer. Deposits contain chalcopyrite and magnetite in a contact zone between granodiorite stocks and metasediments and limestone. Hematite, bornite and secondary copper minerals also present. One sample, the source of which is uncertain, but believed to be from Kasaan Peninsula assayed 0.1% due to allanite and a copper uranite.	Wedow, 1951, p. 63; White and others, 1952, p. 16
12	Dall Bay, south end of Gravina Island	Pods of radioactive feldspar in schist have up to 0.07% U.	Williams, 1956; present report
13	Bokan Mountain District, Prince of Wales Island	The Ross-Adams mine has yielded uranium and thorium ore from a deposit in a peralkaline granite stock. Small samples have assayed up to 3% U308. Past production has averaged almost 1.0% U and 1.0% thorium. Ore minerals are uranothorite and uranoan thorianite.	Eakins, 1970; Freeman, 1963, p. 44—49; MacKevett, 1963; Williams, 1955c

Veinlike Deposits

Vein deposits are of particular interest in Southeastern Alaska because high-grade uranium ore has been produced from a hydrothermal deposit at Bokan Mountain near the southern end of Prince of Wales Island (fig. 2, loc. 13). This deposit constitutes the main stimulus for uranium exploration in Southeastern Alaska. The geology of the area has been mapped and described in detail by MacKevett (1963). The following description of the Bokan Mountain district is taken largely from that report.

The Bokan Mountain district covers about 70 square miles in the Kendrick Bay area. Uranium is associated with light-colored granitic rocks high in quartz and

soda-rich minerals. The following four types of radioactive deposits have been found.

1. A primary segregation of uranium-thorium minerals in a late stage of peralkaline granite magma emplacement and subsequent hydrothermal deposition. This type occurs at the Ross-Adams mine.

2. Syngenetic deposits in pegmatite and aplite dikes.

3. Epigenetic hydrothermal deposits, chiefly open-space filling, but with some replacement.

4. A hydrothermal deposit formed in clastic sedimentary rock by filling of interstices at the Cheri No. 1 prospect.

The principal ore deposit in the Bokan Mountain area is at the Ross-Adams mine, which was discovered in 1955 near the head of Kendrick Bay by Don Ross and Kelly Adams using an airborne Geiger counter. While the ore is not in a vein, it is a hydrothermal deposit. The ore is a uranium-thorium concentration in a peralkaline granite stock, which is roughly circular and about two miles in diameter and forms prominant outcrops.

The peralkaline granite is an unusual variety of igneous rock characteristically high in quartz and the sodium-bearing pyroxene (acmite) and amphibole (riebeckite), which may be present in amounts up to 12 percent. It is generally light gray with an average of about 10 percent dark minerals. Accessory minerals are chiefly zircon, uranothorite, pyrite, xenotime, fluorite, cordierite, and magnetite. Unusual amounts of the minor elements, uranium, thorium, yttrium, lanthanum, niobium, cerium, and other rare earths are present. Aplite and pegmatite dikes genetically related to the Bokan Mountain granite are interesting because some contain uranium, thorium, zirconium, and niobium. Lead-alpha and potassium-argon measurements show the granite to be Late Triassic or Early Jurassic in age (Lamphere, MacKevett, and Stern, 1964). The peralkaline granite stock has been intruded into an older pluton of diorite and monzonite of Ordovician age.

The Ross-Adams ore body is an irregular pipeline body that plunges generally southward. The percentage of uranium minerals decreases gradually outward from a high-grade core, and ore limits are indefinite. Ore mined from an open pit originally contained a high-grade core which averaged over 0.5 percent U_3O_8. A large portion contained 1 percent U_3O_8, and pods contained up to 3 percent U_3O_8. Twelve samples analyzed by the U.S.G.S. yielded from 0.18 to 3.2 percent uranium. High-grade ore can be distinguished by its dark color due to the presence of associated hematite in the granite. The core was surrounded by a zone of lower-grade ore 2 to 20 feet thick that averaged less than 0.5 percent U_3O_8. Information is not available on the tenor of the ore mined later by underground methods or on new ore discovered by recent drilling.

Almost all the ore minerals are primary. They occur both as grains scattered throughout the peralkaline granite and in numerous thin (0.1 to 0.8 mm) veinlets. Anhedral to euhedral grains up to 2 mm wide are typical. The dominant ore minerals are uranothorite (uranium-bearing thorite) and uranoan thorianite (uranium-bearing thorianite). Coffinite, $U(SiO_4)(OH_4)$, is found in minor amounts. Other vein minerals accompanying the ore minerals are abundant hematite and calcite, and lesser amounts of fluorite, pyrite, limonite, galena, quartz, clay minerals, and chlorite.

There is no sharp boundary between the ore and the host granite. The ore zone contains slightly more iron, lead, aluminum, zirconium, titanium, magnesium, calcium, manganese, and arsenic, but less quartz and potassium than the surrounding rock. Most of the ore is out of radioactive equilibrium, but the thorium combines with the uranium in such a way to give the effect of apparent equilibrium.

A total of 60,000 tons of ore averaging almost 1 percent of both U_3O_8 and thorium has been produced by various operators of the Ross-Adams mine by underground and open pit methods. The mine was closed between 1964 and early 1971, when Newmont reopened it. Drilling by Newmont has proven the presence of ore beyond previously known limits and has shown that the structure of the deposit is much more complicated than had been suspected.

Uranium-thorium minerals have been found in small amounts at some other prospects in the area. These minerals include uraninite, uranophane, allanite, possibly davidite or brannerite, and ellsworthite. Only minor amounts of the secondary uranium minerals gummite, sklodowskite, beta uranophane, bassetite, and nowacekite have been reported from the Ross-Adams property. The scarcity of secondary uranium minerals is undoubtedly due to their solubility and the heavy rainfall in the area.

Some claims and prospects in the district are near altered dacite dikes in albitized zones along the margin of the peralkaline granite. Others are on small pegmatite dikes within the granite. Most of these claims are only slightly explored. One prospect was located for fluorite. About eight miles southeast of Bokan Mountain, weak anomalies occur in pegmatites near Gardner Bay. Low radioactivity has been found in altered andesite dikes cutting syenite near Stone Rock Bay about three miles south of Gardner Bay. None of the more common metals associated with the Bokan Mountain uranium-thorium ores appear to be present in commercial amounts, but old copper and gold prospects have also been worked in the past, mostly around Gardner Bay, McLean Arm, and Mallard Bay, 25 to 30 miles southeast of Bokan Mountain. It is possible but not proven that the uranium-thorium ore is related to the copper district on the island (fig. 2).

Tertiary Sediments

Locally in Southeastern Alaska, Tertiary beds overlie Mesozoic and (or) Paleozoic rocks with a pronounced unconformity. Dips vary from 8° in some places at Port Camden to 60° south of Kootznahoo Inlet. The sandstones and conglomerates are poorly sorted, compact, unmetamorphosed, and cross bedded. They consist of an assortment or rock detritus which includes quartz, shale, phyllite, and volcanics. Interbedded coal lenses and plant fossils are common.

Tertiary sediments remain today in the following areas:

1. The Kootznahoo Inlet-Mitchell Bay area near Angoon on the west side of Admiralty Island, where approximately 36 square miles are underlain by sandstones and conglomerates with small amounts of shales and coal.

2. Little Pybus Bay on the southeast side of Admiralty Island, which contains about 5 square miles of sandstone;

3. Port Camden area on Kuiu Island, which contains the most complete section of Tertiary beds; and the nearby Hamilton Bay area of Kupreanof Island;

4. Cleveland Peninsula near Ketchikan, where sediments are exposed for a short distance along shore;

5. Coal Bay on the south side of Kasaan Bay, Prince of Wales Island; and

6. Zarembo Island, along the southwestern coast.

Sedimentary rocks possibly correlative with the sandstones of the Kootznahoo Inlet area are exposed on Pleasant Island in Icy Strait north of Chichagof Island.

In the present study, only three areas of Tertiary sandstones were examined. They are described later under the titles: Kootznahoo Inlet-Mitchell Bay area, Admiralty Island; Port Camden area, Kuiu Island; and Zarembo Island area.

The Tertiary rocks in the six areas consist of volcanics and continental sandstones and conglomerates. The volcanics, including flows, sills, agglomerates, and breccias, are more widespread than the sandstones. In some places the volcanic rocks are interbedded with or overlie the sandstones. The sandstones and conglomerates in Southeastern Alaska occupy troughs created during Paleocene through Miocene time. Though now separated, these strata may once have been parts of a more or less continuous deposit over an extensive area. The sandstone formation of the Kootznahoo Inlet-Mitchell Bay area is probably 5,000 feet thick. A map by Brew, Loney, and Muffler (1966, p. 165) shows an interpretation of Tertiary paleogeography in which a belt 200 miles long and about 30 miles wide is inferred to have extended from the northern part of Admiralty Island to the middle of the western side of Prince of Wales Island. The map shows a core of volcanic rocks surrounded by sandstones and conglomerates.

Uranium in Pegmatite Dikes

Quartz and alkali feldspars frequently separate from cooling magmas to form pegmatite dikes, which may contain concentrations of rare metals, including thorium and uranium. This type of deposit may produce some fine specimens and small amounts of high-grade radioactive material, but there are few pegmatites in the world mined for uranium and so far none in Alaska (Sainsbury, 1957). In the Bokan Mountain uranium-thorium district, radioactivity has been found at scattered prospects in pegmatite dikes as well as in aplite and dacite dikes. Radioactive pegmatites have also been discovered at the BBH claim on Endicott Arm and in pods of feldspar at Dall Bay. These localities were visited during 1970 and are described below under appropriate titles. Regardless of composition, such dikes are probably most valuable as indicators or guides to possibly more extensive deposits rather than being of commercial value in themselves.

Miscellaneous Deposits

Three localities (not listed in table 1) where radioactivity was very low, but where the mineralogy was favorable or rare-earths were detected, may have possibilities for uranium. These are:

1. Admiralty Island, 5 miles west-southwest of the head of Seymour Canal (King Salmon Bay area). Yttrium, zirconium, niobium, thorium(?) and the rare-earth elements lanthanum, cerium, praseodymium, and neodymium were detected by X-ray spectroscopic analysis of heavy minerals from pegmatite veins (Lathram, Pomeroy, Berg, and Loney, 1965, p. R43, R45).

2. Sandy Cove prospect at Glacier Bay. Quartz monzonite bedrock contains allanite plus copper, gold, silver, molybdenum, and bismuth in a mineralized zone (MacKevett, Brew, Hawley, Huff, and Smith 1967, p. 114-115).

3. Goddard Hot Springs area, west side of Baranof Island. Stream gravel concentrates yielded from 0.012 and 0.016 percent equivalent uranium, probably due to thorium in allanite. Radiometric surveys located no radioactive mineral concentrations, but the background over granite areas was considerably above that of metasedimentary rocks (West and Benson, 1955, p. 47-49).

Suggestions for Prospecting

In general, igneous rocks that are late-stage differentiates of granite or syenite, including leucogranite, late rhyolite, aplite, alkalic syenite, and phonolite, have been found to contain the greatest amount of uranium (Faul, 1954, p. 86). Also, uranium is more often found at the border zones of batholiths and peripherial to mineralized districts.

Intrusive rocks are scattered throughout Southeastern Alaska (fig. 3), but geologic mapping of some portions is incomplete or does not distinguish the more acidic granites from the intermediate igneous types. Thus, the most favorable rock types cannot always be pinpointed from published maps alone, and considerable field work may be required.

Veins containing copper, lead, silver, cobalt, and nickel should be checked for radioactivity. In British Columbia, molybdenite is found to be the sulfide most commonly associated with uraninite (Stevenson, 1951, p. 362). Hematite (both the specular and the red varieties, including hematitic jasper) and fluorite are probably the most universal gangue minerals associated with uranium deposits.

The fact that commercial radioactive ore has been found in a soda-rich granite in Southeastern Alaska suggests that similar granites offer the most potential in the region. Alkalic rocks at Tenakee Inlet on the east side of Chichagof Island may offer possibilities.

Areas to consider for uranium exploration in Southeastern Alaska should also include the intrusive rocks bordering mineralized districts, especially the Ketchikan-Prince of Wales Island copper district, the Chichagof copper mining area, and the Hyder district. However, widespread distribution of radiometric showings and sulfide mineralization in Southeastern Alaska indicate that no part of the region can be completely eliminated from prospecting for uranium deposits.

While the characteristics of Tertiary sandstone and conglomerate in Southeastern Alaska do not appear to be favorable for commercial uranium deposits, anomalous radioactivity was detected at a few places. There is no information to indicate that the beds have been tested at depth.

Aerial radiometric surveys from low-flying aircraft are the most rapid means of prospecting large areas, but because of the ruggedness of Southeastern Alaska, the method has its limitations. Geochemical techniques are applicable in some areas. Stream-sediment, soil, and mulch samples can be analyzed for uranium to a sensitivity of 1 ppm. Geobotanical prospecting and the analysis of ashed plant material may be useful in outlining a uranium deposit beneath soil. Field work by

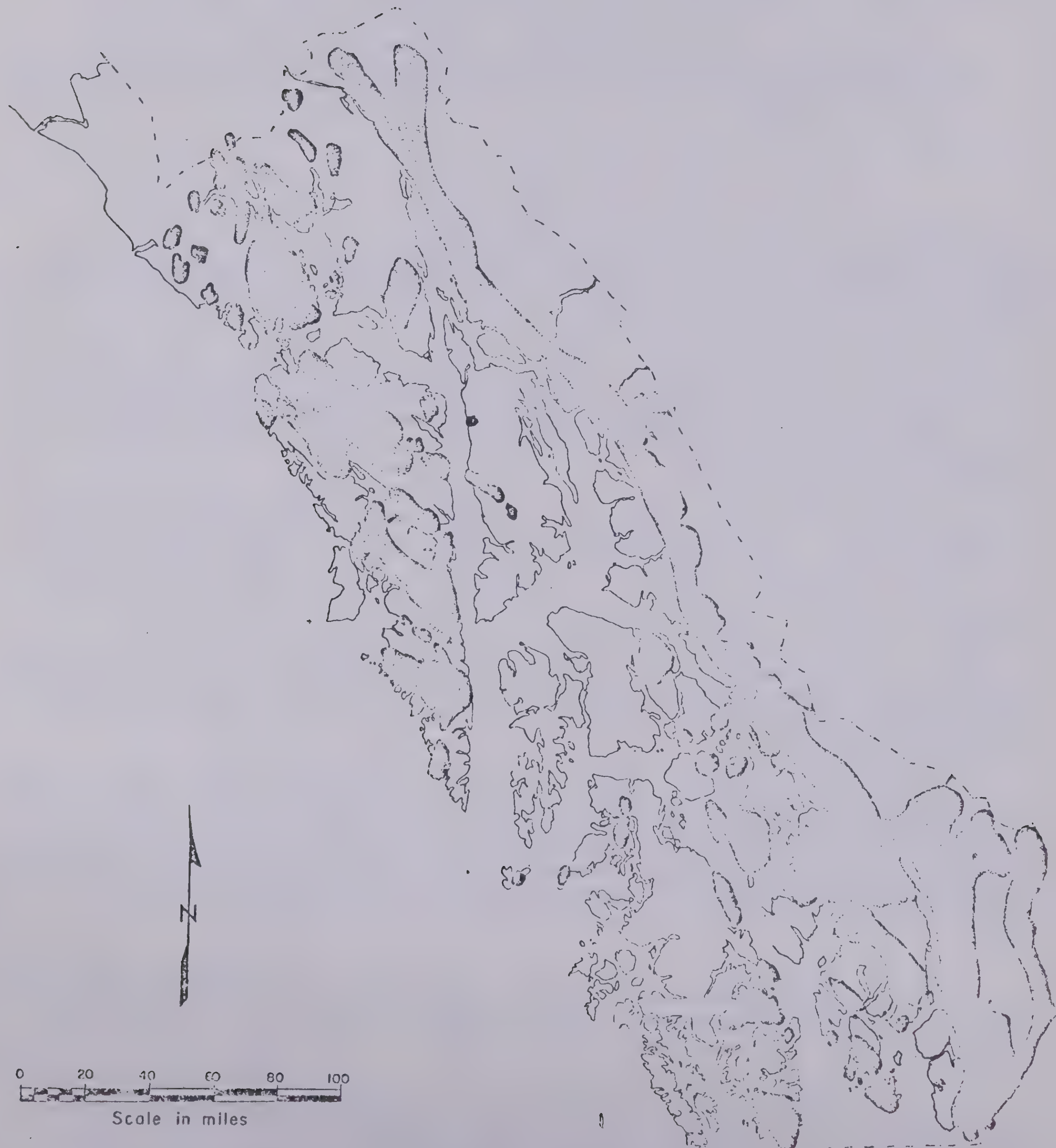

FIGURE 3. Acid and intermediate intrusive rocks of Southeastern Alaska

the author (Eakins, 1970) at the Ross-Adams mine has shown that the deposit has a strong expression in stream sediments and several types of organic material, especially lodgepole pine.

Investigations by the Division in 1970

William Henry Bay Area

The Lucky Six Claim Group is located on the west side of Lynn Canal, approximately 42 miles northwest of Juneau (fig. 1). These claims lie between 1,500 and 2,000 feet above sea level on a ridge 1-1/2 miles south of Endicott River and 2 miles north of the mouth of William Henry Bay. It is a steep, difficult climb on foot from the coast. But above 1,500 feet, the claims are mostly above timber line and the bedrock is exposed in many places. The locality was visited in early June, and about two-thirds of the area occupied by the claims was still snow-covered, prohibiting full examination of the ground.

A radioactive anomaly was detected from the air by prospectors during the 1950's and shallow prospect pits, trenches, and one diamond-drill hole revealed mineralized material. One sample was reported to contain 0.20 percent eU but a commercial deposit was not indicated.

The area considered here lies between William Henry Bay on the south and the Endicott River on the north. The geology of the area has been discussed by Berg (1960, p. B39); Herbert and Race (1964, p. 10; 1965; p. 25-26); MacKevett (1957, p. 175); Matzko and Freeman (1963, p. 44); Mertie (1921, p. 109-112); and Twenhofel, Reed, and Gates (1949, p. 28-30).

The Lucky Six claims are situated on the southeastern edge of a small Tertiary quartz monzonite intrusive that is exposed over an area of approximately three-fourths of a square mile. The intrusive is surrounded by Paleozoic volcanics and metasediments. The general strike of the strata and the dominant structures is north to northwest. However, the geology is complex, the rocks are metamorphosed, and subordinate east-west faults cut the major structures.

About 1/2 mile south of the mouth of the Endicott River, a predominantly carbonate sequence containing argillite and basalt dikes is in contact with an altered sequence of volcanics to the south. The contact is well-exposed on the coast and appears to be a northwest-trending fault. Small diorite and diabase intrusives lie west and north of William Henry Bay.

The intrusive underlying the claims is a light-gray porphyry with feldspar crystals up to 1-1/2 inches long. There is an abundance of altered mica throughout the rock, which is especially noticeable on fractures and in vugs. Some brecciated, fine-grained, siliceous rock was found on the surface. Traces of thorianite in small red patches were reported by Matzko and Freeman (1963), and scattered grains of euxenite were reported by MacKevett (1957). Rare earths were found by Lathram, Loney, Condon and Berg (1959) in a sample containing pyrite, chalcopyrite, galena and sphalerite.

Copper ore has been mined from the Alaska Endicott Mining and Milling Company mine located in the valley 3/4 mile southwest of the head of William Henry Bay at an elevation of 160 feet. Development was done between 1916 and 1920.

Foot traverses with a scintillometer showed the intrusive on which the Lucky Six claims are located to have an overall anomalous amount of radioactivity. The radiometric response increased from 0.01 mr/hr (milliroentgens per hour) or less on the volcanic rocks along the coast to 0.04 mr/hr on the intrusive. The average in the area of the claims was about 0.03 mr/hr, but readings to a maximum of 0.20 mr/hr were obtained in the bottom of prospect pit No. 2.

The small quartz monzonite intrusive just discussed has not been found to be commercial at or near the surface, but the amount of drilling done was probably insufficient to properly evaluate the area. A zinc anomaly obtained in streams draining the ridge south of William Henry Bay is very pronounced, and a copper anomaly is present in the stream south of the Lucky Six claims. It is not known if they have been prospected or sampled more extensively, but on the basis of the anomalies, the upper parts of the drainages in both areas should be examined and sampled.

King Salmon Bay Area, Admiralty Island

The area investigated lies on a subsidiary peak between 1,500 and 3,000 feet elevation 3 miles west of the head of King Salmon Bay, on the northeastern part of Admiralty Island. It lies in the Juneau A-2 quadrangle, approximately 18 miles south of Juneau. A helicopter was chartered in Juneau for transportation to and from the locality.

A geologic map and bedrock descriptions by the U.S. Geological Survey (Lathram, Pomeroy, Berg, and Loney, 1965, p. R43) suggested that the small felsic intrusive near King Salmon Bay should be examined for possible uranium occurrences.

West of the head of Seymour Canal an area of about 50 square miles of Paleozoic and Mesozoic migmatite, gneiss and schist contains, near its center, a felsic intrusive about a mile in diameter. The intrusive consists of allanite, biotite granite, biotite-quartz monzonite, and quartz-albite-microcline pegmatite. Rare-earth elements and possibly a trace of thorium in pegmatite dikes were located less than 2 miles north of the granite (Lathram, Pomeroy, Berg, and Loney, 1965, p. R43). The composition of the granite intrusive suggested the possibility of uranium. Some of the granitic outcrops weather nearly white. No sulfide minerals were found except a small amount of pyrite in migmatite near the margins of the intrusive. Iron staining was heavy near the head of a draw on the north side of the peak at 2,200 feet, and small veinlets and pods of white, massive quartz are present in the migmatite contacts at two or three locations. The largest quartz pod seen was 2.5 feet thick. A pegmatite dike 1 x 10 feet containing quartz, feldspar, and biotite was found to be barren of sulfides and radioactivity. The pegmatite dikes reported by the U.S. Geological Survey to the north were not examined, and no mineral deposits or prospects are known to be in the area visited by the author.

No significant radioactivity was detected at the felsic intrusive near King Salmon Bay, and prospecting for uranium there is not encouraged.

Tracy Arm Area, Chichagof Island

William Huff (written communication, 1970) reported that while using an airborne scintillometer he encountered a radiometric anomaly on the east side of the entrance to Tracy Arm. The location was estimated by him to be approximately

57° 50' N., 33° 33' W. at an elevation of about 1,500 feet. This is in the Sumdum D-5 quadrangle approximately 50 miles southeast of Juneau (fig. 1).

The area is occupied by strongly foliated, northwest-trending schists and phyllites, and is near the western margin of the Coast Range batholith. The extensive Sumdum copper-zinc prospect is located 4 miles southeast at an elevation of 4,000 feet on both sides of and beneath the Sumdum Glacier (MacKevett and Blake, 1964). Several prospects containing copper, lead, zinc, and gold are on Tracy and Endicott Arm (Gault and Fellows, 1953; Herreid, 1962; Race, 1962).

The author visited the area for 1 day but never reached the location where the radioactive anomaly was believed to be. A foot traverse was made from the east shore of Tracy Arm, near its mouth, to an elevation of 1,000 feet. Scintillometer readings on the schist were between 0.005 and 0.01 mr/hr. It is possible that the radioactive anomaly reportedly detected from the air was due to outcrops of granodiorite containing considerably higher radioactivity than the surrounding schist. Dioritic boulders contain much visible disseminated pyrite and magnetite.

Trap Bay Area, Chichagof Island

Trap Bay is an indentation on the south coast of Tenakee Inlet, Chichagof Island, about three miles from Chatham Strait. The area visited is near the junction of the Sitka C-3, C-4, B-3, and B-4 quadrangles, 23 miles northwest of the village of Angoon. The area can be reached by boat or float plane. The Trap Bay locality was visited to examine a radioactive anomaly detected from the air while flying the Kook Lake area with a scintillometer.

The geology of the Trap Bay region has been mapped by Loney, Berg, Pomeroy and Brew (1963). Bedrock along the coast on the east side of the bay is Silurian(?) and Devonian(?) graywacke and argillite. These rocks are overlain by a thick unit of pebble to cobble conglomerate on the ridge east of Trap Bay. A stock of granodiorite crops out on the west side of Trap Bay. The east side of the stock along the valley at the head of Trap Bay and on the west side of the bay is bordered by a narrow zone of hornfels. Devonian limestone forms conspicuous bluffs on the north side of Tenakee Inlet and a northwest-trending belt west of Trap Bay.

Foot traverses with a scintillometer along the shores of Trap Bay, Tenakee Inlet, and up a short stream draining into Trap Bay showed that coarse conglomerate on the ridge south of Tenakee Inlet produces an abnormally high radioactive background of 0.015 to 0.025 mr/hr. Argillite and limestone bedrock in the area produced less than 0.010 mr/hr. The strongest radioactivity, 0.040 mr/hr, was found in crushed material containing iron oxides in the sheared zone cutting granodiorite at the head of Trap Bay. No radioactive minerals could be isolated and the radioactivity was limited to areas a few inches across on fracture surfaces.

The anomaly detected at Trap Bay from the air apparently is due to the relatively high radioactivity of coarse conglomerate on the hill east of the bay. The source of the radioactivity is probably the felsic igneous debris so abundant in the conglomerate. The radioactivity at the shear zone near the head of the bay is believed to be due to a trace of uranium or thorium, but it was not in sufficient quantity to encourage prospecting for these elements.

Kook Lake Area, Chichagof Island

Kook Lake is located on the eastern side of Chichagof Island one mile inland from the head of Basket Bay. It is in the Sitka C-3 and C-4 quadrangles about 45 miles southwest of Juneau. Float plane is the most practical means of reaching the lake. A U.S. Forest Service cabin is maintained near a good beach at the west end of the lake. The village of Tenakee on Tenakee Inlet lies approximately 11 miles to the northwest. The terrain consists of steep mountains which rise abruptly to altitudes of 2,500 feet within 1-1/2 miles of the lake.

The Kook Lake area was chosen for examination because sodalite syenite and nepheline syenite mapped by Loney, Berg, Pomeroy, and Brew (1963) were considered to be favorable rock types for radioactive minerals.

Foot traverses with a scintillometer were made along streams south of Kook Lake. The radiometric background was between 0,005 and 0.010 mr/hr. A response up to 0.050 mr/hr was encountered at an elevation of 500 feet on the south side of Kook Lake where fractures cut basic dikes. Outcrops of syenite(?) in this area gave readings up to 0.020 mr/hr.

Another low-grade anomaly of 0.030 mr/hr was found at an elevation of 450 feet near the southeast end of the lake. In contrast, limestone and conglomerate beds in that area produced only 0.005 mr/hr.

A one-hour flight in a light plane with a scintillometer probe tied outside the cabin was made over the east side of Chichagof Island from Tenakee Inlet south to Kitkoh Bay in an attempt to locate any radiometric anomalies present in the various intrusives in the area. The terrain flown was very rugged and flying conditions were poor. The highest readings, 180 counts per minute were obtained over a 3,000-foot mountain on the south side of an unnamed lake two miles south of Basket Lake, and over the ridge just east of Trap Bay near the entrance of Tenakee Inlet. Only the anomaly at Trap Bay was checked on the ground.

The radiometric responses encountered near Kook Lake did not indicate uranium deposits. However, above-average radioactivity was generally found in the country rocks and the intrusives occupying a much larger portion of the east side of Chichagof Island appear to offer possibilities. The flight over these was inadequate, and more controlled aerial surveys with the proper equipment might produce more positive results.

A sample of light-colored granitic rock from 1/2 mile south of the west end of Kook Lake was analyzed for uranium and showed 10 ppm eU, which is twice the average for acid igneous rocks. Anomalous values for lead and zinc from stream-sediment samples suggest that the area could contain concentrations of base metals.

Kootznahoo Inlet-Mitchell Bay Area, Admiralty Island

Kootznahoo Inlet and Mitchell Bay are in an area of low relief on the west side of Admiralty Island near its midpoint in the Sitka B-2 and C-2 quadrangles. Angoon, the only permanently inhabited village on the island, is near the entrance of Kootznahoo Inlet about 43 miles northwest of Sitka. Angoon is served by scheduled flights from Juneau and Sitka. Landings by chartered float planes may be made anywhere in Mitchell Bay. Numerous narrow waterways make it possible to examine well-exposed Tertiary sandstones along the shores by small boat. However, very strong

tidal currents in Kootznahoo Inlet and Davis Creek make it advisable for small craft to travel these narrows during slack tide.

No metallic mineral deposits have been discovered in the area. Exploration has been restricted to the search for coal, which has been found in the lower part of the Tertiary sequence. Brief examinations of the sediments in the area, possibly for uranium, are rumored to have been made in recent years by petroleum company geologists.

The following summary of the geology of the Kootznahoo-Mitchell Bay area is taken from Buddington and Chapin (1929, p. 261-263), Lathram, Pomeroy, Berg, and Loney (1965), and Smith (1939). Approximately 36 square miles are occupied by nonmarine sediments belonging to the Kootznahoo Formation, which is present in the low areas around Kootznahoo Inlet, Mitchell Bay, Kanalku Bay, and Davis Creek, and on the low hills north of Kootznahoo Inlet. Fossil flora indicate the age of the formation to be Paleocene through Miocene. Its total thickness is believed to be about 5,000 feet. Its lithology is described as predominantly pebble to cobble conglomerate, fine-grained to arkosic sandstone, lithic sandstone, calcareous siltstone, calcareous shale, lignite and subbituminous coal. Carbonized plant material is common.

The Tertiary sediments overlie, with angular unconformity, Devonian schist and phyllite and undifferentiated Mesozoic metamorphic rocks. Conspicuous lineation of channels and topographic features are evident on topographic maps and aerial photos. Some of the channels are apparently occupied by large faults. Tilting of the beds is thought to be due mostly to faulting and central-basin subsidence rather than to folding. Dips average about 30°, but vary from a few degrees to 45°.

The coarseness, poor sorting, and grain angularity of much of the Kootznahoo Formation indicate deposition near its source. Some beds of conglomerate around Mitchell Bay contain boulders up to 12 inches in diameter. These rocks represent consolidated alluvial fans formed in an intermontane basin. Fine-grained material with silt and coal near the middle and southern part of the basin indicate ancient swamps. An apparent northward increase in coarseness of the sediments and cross-bedding, observed during the Division's uranium investigation, suggest that their source was north of the basin.

Intrusive quartz diorite and granodiorite form a batholith occupying approximately 150 square miles beginning about 5 miles north of Mitchell Bay. Smaller intrusives are present at the northwest end and south side of Mitchell Bay.

No significant radioactivity was encountered in the Kootznahoo Inlet-Mitchell Bay area. The highest scintillometer reading encountered was 0.02 mr/hr or about three times the background. This was found in an oxidixed zone cutting schist approximately 100 yards from shore up a stream entering Mitchell Bay just north of the mouth of Davis Creek, on the east side.

About 3 miles north of the mouth of Kootznahoo Inlet a large stream enters Chatham Strait. A foot traverse up this stream was made to examine the Tertiary rocks present on a 1,500-foot hill one mile from shore. A maximum of 0.015 mr/hr was found in schist at elevations of 100 and 250 feet. The background was 0.006 mr/hr. Very few sandstone outcrops were observed.

Radiometric readings and mineralogy of the nonmarine Tertiary outcrops in the Kootznahoo Inlet-Mitchell Bay area did not suggest the possibility of radioactive deposits. Certain features generally considered to be characteristic of uranium-bearing sandstones such as the presence of pyrite, vanadium, copper, arsenic, good porosity, and alteration or bleaching, were not observed.

BBH Uranium Claim, Endicott Arm Area

The BBH No. 1 uranium claim is near the east shore of a short branch of Endicott Arm 2 miles below the present terminus of North Dawes Glacier. It is about 75 miles southeast of Juneau in the Sumdum C-3 and C-4 quadrangles. The prospect is on a stream draining a steep slope on the east side of the inlet.

The BBH No. 1 claim was staked in 1955. Two samples submitted to the Territorial Assay Office showed 0.03 percent and 0.04 percent eU, and 0.015 percent and 0.032 percent U by fluorimeter. These results led to an examination of the claim by the Territorial Department of Mines (Williams, 1955a). Samples collected by Williams had lower values: 0.01 percent, 0.002 percent, 0.002 percent and 0.011 percent eU. Apparently no further exploration or development work was done on the property, but William Huff (written commun., 1969) reported that fluorescent uranium minerals are present on a ridge south of Endicott Arm.

The BBH claim is near the western margin of the Coast Range batholith. Bedrock at the claim is Cretaceous granodiorite or quartz diorite. The batholith is bounded on the west by a belt of metamorphic rocks and outlying intrusives of upper Paleozoic to Mesozoic age, which contain numerous old claims and prospects. Mapping across this belt north of Juneau (Forbes, 1959) shows a progressive increase in metamorphic grade eastward toward the batholith. Gradational layering of schist and gneiss are present. Forbes showed that the gneiss is a schist which as been transformed by the late injection of Na, SiO_2, and minor K. Herreid (1962, p. 6) found no disruption of minor structures along contacts between gneiss and quartz diorite, indicating a passive introduction of the igneous rock.

At the BBH claim, small pegmatite pods and lenses within a medium-gray, medium-grained quartz diorite are radioactive. The quartz diorite there is slightly foliated.

Several mines and prospects are located 10 to 25 miles west of the BBH claim. No mines are active, but several prospects are. The better known properties include a zinc-copper lode on Tracy Arm, which was estimated to average 3.2 percent zinc, 1.5 percent copper, plus a little gold and silver (Berg and Cobb, 1967). Near Sumdum Glacier a copper-zinc lode was discovered in 1958 and explored during 1959. The mineralized zone may extend 2 miles (MacKevett and Blake, 1964). The Sumdum Chief mine on Endicott Arm is said to have produced about $50,000 in gold prior to closing in 1904. Underground exploration has been done on silver-and gold-bearing lodes near Point Astley. Near the head of Windham Bay, about 12 miles west of the head of Endicott Arm, a number of placer and lode gold deposits were worked between 1900 and 1937. The lodes are quartz stringers in schist, which contain pyrite, pyrrhotite, galena, sphalerite, arsenopyrite, chalcopyrite, and free gold (Berg and Cobb, 1967, p. 191).

Radioactive pegmatitic zones are exposed at the BBH claim along a steep stream from the shore to an elevation of about 150 feet. They lie within an area approximately 100 to 250 feet. Four small pods or lenses of pegmatite up

to 12 feet long roughly parallel cleavage planes in granodiorite. The radioactive mineral was tentatively identified as uraninite (Williams 1955a). Country rock at the property normally is a fresh gray granodiorite, but it is partly altered to a brown, softer material. Alteration zones tend N. 60-70^{o} E., parallel to cleavage. Minerals in the pegmatite identifiable in hand specimens are K-feldspar, quartz, pyrite, and biotite which was found in plates up to 10 inches across. Two samples of pegmatite from the BBH claim assayed in 1970 yielded 35 and 45 ppm uranium.

Foot traverses along the shores and streams bordering the north branch of Endicott Arm and along the river to the terminus of North Dawes glacier revealed that small pegmatites similar to those of the BBH claim are fairly common in the area. None of these was more than 30 feet long or 2 feet wide. Most of the pegmatites in the area produced an appreciable radiometric response, but significant alteration and rather large amounts of pyrite were seen only at the BBH property.

A copper-bearing vein at Point Astley near the south side of the entrance to Endicott Arm was studied by Houston, Bates, Velikanje and Wedow (1958, p. 25). Slight radioactivity was reported at one point underground. A 2-foot sample assayed 0.006 percent equivalent uranium, but no radioactive minerals were identified. Examination of the BBH claim with a scintillometer produced a maximum response of 0.1 mr/hr, which was about ten times the average background of 0.01 mr/hr over the granodiorite. Most of the pegmatites on the claim and at other places in the general area yielded around 0.05 mr/hr, but one pegmatite along the river draining North Dawes Glacier also gave a 0.1 mr/hr reading at one point. Radioactivity of schist was lower than that of granodiorite, usually less than 0.005 mr/hr.

Pegmatites in the area do not appear to warrant further exploration for uranium. However, the fact that they do display a certain amount of radioactivity, combined with the possible presence of uranium 4 miles southwest of the BBH claim, may indicate that this region, between the Coast Range batholith and the Pacific Ocean, deserves more study. Sulfide deposits, especially those containing copper and silver west of this claim, also may be favorable indicators, as uranium sometimes is associated with such deposits or is peripheral to districts that contain them.

Port Camden Area, Kuiu Island

The Port Camden area lies in the Petersburg D-6 quadrangle 36 miles west of Petersburg. The area visited in on the west side of Port Camden on Kuiu Island, and can be reached by boat or float plane.

The Port Camden area is underlain by gently dipping Tertiary volcanics and clastic sediments.

These rocks presumably overlie strongly folded Paleozoic sedimentary and metamorphic rocks that are exposed to the west on Kuiu Island and to the east in the vicinity of Duncan Canal on Kupreanof Island. The sediments at Port Camden have been discussed by Wright and Wright (1908, p. 59-60), Buddington and Chapin (1929, p. 261-263, 353), and Muffler (1967, p. C47-C50). Buddington and Chapin give an approximate total thickness of 2,850 feet for the Tertiary sequence at Port Camden. The upper 1,500 feet are volcanic rocks and the lower 1,350 feet consist of nonmarine sandstone and conglomerate with intercalated sills.

Nonmarine sandstones and conglomerates are exposed along the northern edge of the Tertiary deposits, from Kadak Bay south for about 5 miles. Similar material

is present 5 to 8 miles to the northeast on the south side of Hamilton Bay east of Keku Strait. That area is one of very low relief and many swamps, and was not examined.

Radiometric testing with a scintillometer was done on foot, principally along the east side of Kuiu Island from Kadak Bay to a point about five miles south. The readings range from a low of .003 mr/hr to a maximum of .04 mr/hr, a ratio of 13 to 1. The relatively high response of .025 mr/hr obtained at a conspicuous felsite bluff 1/2 mile from the coast is attributed to a high potassium content rather than uranium.

The strongest anomaly, .02 to .04 mr/hr, was found along a 4-inch bed of fine-grained sandstone within a 25-foot bluff of massive sandstone 1/3 mile south of a prominent point south of the mouth of Kadak Bay. Two chemical assays of this sandstone revealed 11 and 12 ppm uranium, or about 5 times the average uranium content of sedimentary rocks. The radioactive seam is about 5 feet above beach level at its northern end, but dips gently south for about 100 feet. It is soft and red on weathered surfaces, but is hard and gray on fresh breaks. It has a very high magnetite content, estimated visually as 30 percent. Fragments of rock up to 1/2 inch in diameter will cling to a pocket magnet. Other visible minerals include pyrite, quartz, plagioclase, and mica flakes in a groundmass of very fine-grained altered material. The adjacent sandstone is light brown, softer, and lacks visible magnetite or pyrite. The sandstone immediately above and below the radioactive seam gave .008 mr/hr and .005 mr/hr, respectively.

Other slightly anomalous readings from sandstone in the area ranged from .010 to .023 mr/hr. These were found along streams west of Port Camden near the southern end of the area mapped. Chemical assays of these zones yielded less than 2 ppm uranium.

Radioactivity in the thin bed of magnetic sandstone is the strongest found by the author in sedimentary rock in Southeastern Alaska. While the level of radioactivity of this zone does not necessarily indicate commercial possibilities, it shows that a certain degree of concentration can take place in sandstone in this region. The bed probably represents a local placer accumulation of heavy minerals. The source of those minerals is uncertain, but they may have been derived from a granitic rock containing anomalous amounts of radioactive minerals.

Castle Islands, Duncan Canal

A barite deposit on the east side of Castle Island in Duncan Canal 14 miles southwest of Petersburg (fig. 1, area 9) is currently being mined by Alaska Barite Company for use as mud weighting material by the petroleum industry in Alaska. The Castle Island operation was visited during the course of the uranium project, but no radioactivity was detected at the barite deposit, or on any of the nearby islands. Bedrock includes Devonian schist, greenstone, limestone (which is the host for the barite), and Tertiary volcanics.

Virginia Lake Area, Wrangell District

Virginia Lake is on the mainland about 8 miles east of Wrangell townsite. The lake is approximately 2 miles long and lies 3/4 mile from tidewater at an elevation of 100 feet. The most convenient means of access is by float plane. The U.S. Forest Service maintains a cabin near a sandy beach at the northeast end. A foot

trail follows Mill Creek from the coast to the lower end of the lake.

Uranium investigation was limited to bedrock exposures within a short distance of the Virginia Lake shoreline. There are no known mineral deposits within that area. However, a mineralized belt lies between 2 and 4 miles east of Virginia Lake, where considerable exploration and some underground work has been done on sulfide deposits. The visit to Virginia Lake was prompted by reported radioactivity on the north side of the Lake (William Huff, written commun., 1969).

The general geology of the region and mineral deposits east of Virginia Lake have been described by Buddington (1923, p. 58-63), Wright and Wright (1908, p. 188-190), and Gault, Rossman, Flint and Ray (1953, p. 15-55). Bedrock surrounding the lake is schist, marble, and quartz diorite.

Radiometric checks were made on bedrock along the shore of Virginia Lake and streams draining into the lake. Typical scintillometer responses of 0.007 to 0.012 mr/hr were obtained for both quartz diorite and schist bedrock. The limestone bed yielded only 0.002 mr/hr.

An anomalous zone was found in the schist along one stream north of the lake. This was examined from the shore up to an elevation of 350 feet. Readings ranged from 0.020 to 0.035 mr/hr, or about four times average background. This zone apparently extends south to include an island near the south shore where the average radioactivity was about 0.025 mr/hr. It is about on strike with the limestone but they are probably separated by a fault.

No visible mineralized material or fault is associated with the anomaly. It is assumed that this zone contains the radioactivity reported by Huff, which is mentioned above. A chemical assay of a sample of the radioactive schist showed only 3 ppm uranium. This is not adequate to account for the radiometric anomaly, which may be due to either high potassium or traces of thorium.

In conclusion, a weak radioactive zone in schist parallel to regional structure extends from an island near the south shore of Virginia Lake northwest to a point at least 350 feet above sea level in a stream valley north of the lake. The source of the radioactivity was not identified. The low level of radioactivity and the fact that it is not concentrated suggest that the possibilities for finding much uranium in the area examined are poor. Prospecting for radioactive materials near mineralized areas east of Virginia Lake might be more worthwhile.

Zarembo Island Area

The southwest coast of Zarembo Island from Macnamara Point southwest to a point opposite the south end of Bushy Island has been reported to contain minor uranium showings. There has been no mining in the area examined, but fluorite veins have been known along the shores for many years (Buddington, 1923, p. 75).

Zarembo Island is 25 miles southwest of Wrangell along Clarence Strait in the Petersburg quadrangle. It can be reached by boat or float plane.

The Tertiary rocks of Zarembo Island have been described by Buddington (1923, p. 75), Buddington and Chapin (1929, p. 261, 266, 272, 273), and Roehm (1942, p. 14; 1945, p. 11-12). The southwest coast of Zarembo Island is covered with Tertiary

rocks, which include predominantly greenish lavas, agglomerates, tuffs, and more recent dikes. However, Tertiary sandstones, shales, and conglomerates are present for a distance of 4 miles, from a point 1/2 mile south of Macnamara Point to a point on the coast approximately east of the north end of Bushy Island. The sandstone contains quartz, feldspar, and altered mica. At some locations it is conglomeratic and displays good cross bedding. Interbedded shaly material is common and often contains fossil leaves. The sediments strike northwest and dip 20° to 40° E. Both felsic and basaltic dikes cut the sediments. Shear zones and fractures generally trend east-west.

Houston, Bates, Velikanje and Wedow (1958, p. 24) sampled granite at Round Point at the southern tip of Zarembo Island. The granite assayed 0.004 percent eU.

White, West, Tolbert, Nelson and Houston (1952, p. 16) sampled shear zones in basaltic, andesitic, and rhyolitic volcanic rocks in two areas on the west side of Zarembo Island in 1951. They reported assays generally less than 0.001 percent eU, but locally the felsic rocks contained up to 0.005 percent.

Fluorite veins cutting lava on the west coast of Zarembo Island have been described by Buddington (1923, p. 75) and Roehm (1942, p. 14; 1945, p. 11-12). These include irregular fracture fillings of quartz and fluorite at Point Nesbit, at a point 3 miles northeast of Macnamara Point, and at a locality east of Bushy Island. The author examined the fluorite locality east of Bushy Island. Quartz and fluorite veins vary from 1 inch to 1 foot in width and trend roughly east-west. The quartz was deposited before fluorite. The veins were not always completely filled, so that fluorite frequently was euhedral.

Scintillometer readings ranged from 0.005 to 0.025 mr/hr. The average background over sediments was about 0.008 mr/hr. The highest readings were obtained over sandstone on the beach and on a small island close to shore about one mile south of Macnamara Point. This was a definite anomaly, but a chemical assay of this material showed only 2 ppm U. Thorium or potassium probably caused the anomalous readings. Volcanic tuffs and felsic dikes gave readings up to 0.02 mr/hr, which are fairly common to felsic rocks. The tuffaceous material may be the source of a slight concentration of radioactive minerals in the sandstone.

Salmon Bay Area, Prince of Wales Island

The Salmon Bay area is on the northwest coast of Prince of Wales Island, about 35 miles southwest of Wrangell, in the Petersburg B-4 quadrangle. The area can be reached by boat or float plane. Salmon Bay is frequently used as an overnight harbor for fishing boats.

On May 30, 1950, John Wandve of Ketchikan submitted to the Alaska Territorial Department of Mines samples of red, jaspery rock from the northwest coast of Prince of Wales Island. These samples showed significant radioactivity and averaged 0.01 percent eU (Glover, 1951, p. 1). In July, 1951, Glover and members of the U.S. Geological Survey Alaska Trace Elements Unit examined the area and found additional radioactive material both north and south of the original discovery near Salmon Bay (Houston, 1952, p. 5). Claims were staked by various prospectors, but no subsurface exploration was done. Interest in the area led to a more detailed study by Houston, Bates, Velikanje and Wedow (1958, p. 6-23) during the summer of 1952.

Geology of the Salmon Bay area was mapped by Buddington and Chapin (1929, pl. 1). Houston (1952), Houston, Bates, Velikanje, and Wedow (1958, p. 3-23), Glover (1951),

and Wedow and others (1953, p. 6, 9, 13) discussed the general geology in reports on radioactive veins in the area. The following summary of the geology is mostly taken from those sources.

The predominant bedrock unit in the area discussed is a thick graywacke formation of Silurian age and is the host for radioactive veins. The graywacke sequence includes beds of indurated sandstone, shale, and conglomerate composed of pebbles and cobbles of greenstone, limestone, and granitic rock. A bed of conglomerate 300 to 400 feet thick is present at the base of the sequence. Part of the graywacke displays beds a few inches to several feet thick, but other parts are massive and difficult to distinguish from volcanic rock. The strike and dip average about N. 15° W. and 45° W., respectively. The graywacke is composed mostly of feldspar, chert, quartz, and iron oxides, but parts of it are very limy. The iron oxides impart a dark reddish color. Many fine-grained, steeply dipping basalt and lamprophyre dikes cut the graywacke. They vary in thickness from a few inches to 60 feet. Their age is believed to range from Cretaceous to Tertiary.

Thick, light-colored massive limestone of Silurian age underlies the graywacke 8 miles southeast of the entrance to Salmon Bay. Similar rock is exposed just west of Point Colpoys on the north coast of the Prince of Wales Island.

The only granitoid rock seen in the Salmon Bay area during the 1970 investigation was a dark quartz diorite or granodiorite which forms the Rookery Island in Clarence Strait.

The only mineral deposits known in the immediate vicinity of Salmon Bay are radioactive carbonate-hematite veins and nonradioactive rare-earth carbonate veins found along 8 miles of coast between Point Colpeys and Pitcher Island. Veins having the strongest radioactivity are those on the east side of Fishery Island and on Pitcher Island. Most of the veins can be examined only at low tide. The radioactive veins are from 2 inches to 2-1/2 feet wide, generally straight and steeply dipping. Their strikes are mostly north to N. 30° W. They can be traced for 200 to 300 feet, but often they extend beneath water or soil and vegetation, so their true lengths cannot be measured easily. The vein material and the host rock are both stained about the same dark color. However, the veins can be traced as straight, shallow notches, because the carbonate material erodes more easily than the argillite. There is no difference in appearance between the highly radioactive parts of the veins and those parts with little or no radioactivity. Walls of the veins show some alteration and low radioactivity.

Composition of the veins was reported by Houston, Bates, Velikanje and Wedow (1958, table 1) as 80 to 99 percent dolomite-ankerite. Alkalic feldspar is the next most abundant mineral, composing up to 10 percent of the vein material. Red to specular hematite was found in small amounts in most veins. Pyrite is always present. A number of accessory minerals were found in trace amounts. The presence of fluorite, hematite and chalcedony are considered to be aids to prospecting because these minerals are frequently associated with uranium.

Thorite, monazite, zircon and apatite are the only radioactive minerals identified and are present only in small amounts. Radioactive minerals could not be determined in some samples, but it was concluded that most radioactivity is due to thorium in thorite and monazite. Uranium appears to be present only in trace amounts. The highest grade sample was a grab sample taken near the entrance to

Salmon Bay, which averaged 0.13 percent equivalent uranium and 0.64 percent equivalent thorium (Houston, Bates, Velikanje and Wedow, 1958, p. 12, 13). One channel sample taken along 100 feet of the Paystreak vein on Pitcher Island averaged 0.034 percent equivalent uranium and 0.16 percent thorium (Houston, Bates, Velikanje and Wedow, 1958, p. 18). Assays were run on three of the most radioactive zones sampled by the present author in 1970. These produced only 10, 7, and 3 ppm uranium, confirming that the radioactivity is due principally to thorium. However, due to the high solubility of uranium, it may have been leached out of the near-surface portion of the veins.

Besides the radioactive veins, larger ones containing rare-earths, fluor-carbonate and hematite have been found one mile north of the entrance to Salmon Bay and on Pitcher Island. These are as much as 10 feet wide and 400 feet long. Assays reported to Houston, Bates, Velikanje and Wedow (1958, p. 19) show a maximum rare-earth oxide content of 5.0 percent. Fourteen other assays ranged from 0.07 percent to 1.95 percent rare-earth oxides. The minerals parisite and bastnaesite were identified.

The radiometric values at Salmon Bay were the strongest encountered in 1970. The background count measured with a scintillometer (Precision Radiation Instrument 117-B) was 0.015 mr/hr. Radioactivity of the richest spots on the veins reached 5.0 mr/hr and up to 11,500 counts per minute with a four-channel spectrometer. Radioactivity varies along the veins but was found to be highest in narrow parts and particularly at the junctions of veins. Radioactivity of the dioritic rock on the Rookery Islands was 0.05 mr/hr, which is considered to be about normal for this types of igneous rock.

Control for emplacement of the radioactive veins is principally structural. Veins appear to be fillings in a particular set of fractures. The occurrence of radioactive veins only in graywacke is probably due to the presence of open fractures during a time of hydrothermal activity in the area. Houston, Bates, Velikanje and Wedow (1958, p. 22) suggested that the carbonate-hematite veins are actually carbonatites.

The nearest plutonic rock, not mentioned in earlier reports, is the grano-diorite of the Rookery Island. It is not known what relation this rock may have to the veins along the shore of Prince of Wales Island.

Information is limited due to a lack of geologic mapping on the northern part of the island and the dense vegetation and soil cover there. Careful work might reveal a wider distribution of veins and disclose their relation to plutonic activity. The known veins are too low in uranium, thorium, and rare-earths to be of commercial value at present, and their mineralogy does not indicate that values would increase greatly with depth. Some increase in uranium may be expected though, because of near-surface leaching. The veins are of interest principally because they could be related to undiscovered mineralization in the interior of Prince of Wales Island and because high-grade uranium ore has been found near Kendrick Bay at the southern end of the island.

Devilfish Bay Area, Kosciusko Island

Devilfish Bay is on the east side of Kosciusko Island west of El Capitan Passage. It is in the Petersburg quadrangle about 50 miles south of Petersburg, and can be reached by boat or float plane. The area of primary interest is near the southwestern end of Devilfish Bay, where there are several mining claims and prospect pits.

Claims were staked (by Ketchikan prospectors) for copper and molybdenum near the head of Devilfish Bay in 1962. Assessment work and additional exploration were subsequently done. Herreid and Kaufman (1964, p. 9) made a brief visit to the area and described three prospects located near the head of Devilfish Bay. A major company staked claims in the area in 1969. Prospector William Huff noted anomalous radioactivity in the area and suggested that an investigation for uranium was justified.

Devilfish Bay lies on the east side of the Dry Pass dioritic batholith. Silurian graywacke and limestone are present as inclusions within the granodiorite near the southwest end of the bay. Reaction between the sediments and the intrusive rocks has formed masses of brown and greenish garnet and marble. Some well-developed garnet crystals up to 1 inch in diameter are present in the marble. Small deposits containing metallic minerals have been found in the contact metamorphic zone. Irregular pegmatite dikes within the diorite are exposed along the shore at the southwest end of the bay. These strike southwest and are up to 20 feet long.

Anomalous radioactivity was found at several points within the area examined. The average background over exposed granodiorite was approximately 0.008 mr/hr. The pegmatite dikes along the shore registered up to 0.025 mr/hr. Exposed granodiorite at an elevation of 130 feet on the south side of the bay produced 0.03 mr/hr. The copper-molybdenum prospect contains one spot that registered 0.045 mr/hr, the highest reading in the area. Most of the material in the prospect pit yielded 0.025 mr/hr or less. A chemical assay of a sample from the prospect produced a value of 8 ppm uranium, about twice that of the average acid igneous rock. The radioactive mineral was not identified.

Small pits and trenches have been dug to explore the locality. Two prospects closest to the bay contain pyrite, chalcopyrite and a little molybdenum. The third contains massive granular magnetite with minor chalcopyrite.

In summary, radioactive anomalies were found at Devilfish Bay, especially the 0.045 mr/hr reading obtained in the prospect pit containing pyrite, chalcopyrite and molybdenum. The mineralogy and general geology, however, do not suggest the presence of sufficient uranium to justify exploration for this element. The anomalous radioactivity does illustrate how it may be associated with various mineral deposits and used as a general prospecting aid.

Dall Bay, Gravina Island

A uranium prospect is located on the east side of Dall Head near the southern end of Gravina Island in the Ketchikan A-6 quadrangle, 13 miles south of Ketchikan. Radioactive zones are exposed on the shore on the west side and near the north end of a small peninsula extending into Dall Bay. The area can be reached by boat or float plane.

The southern part of Gravina Island was an area of considerable prospecting and some mine development prior to 1915. During the winter of 1955, Ketchikan prospectors discovered radioactivity south of the entrance to Dall Bay. Several lode claims, called the Black Jack group after the Black Jack Mining Company, were staked. Radioactive samples received by the Alaska Territorial Department of Mines led to an examination of the property (Williams, 1956). Assays on file at the Alaska Division of Geological Surveys office record values up to 0.07 percent uranium, but one report mentions that one sample carried several percent equivalent uranium.

During 1951, prior to the discovery of radioactivity on the Black Jack claims, White, West, Tolbert, Nelson, and Houston (1952, p. 15) made a reconnaissance survey for uranium along the southeast side of Gravina Island. They reported a maximum of 0.005 percent equivalent uranium in felsic volcanic rocks, but evidently did not find the radioactive material.

Buddington and Chapin (1929, pl. 1) mapped the bedrock surrounding Dall Bay as Upper Jurassic or Lower Cretaceous quartz diorite to granodiorite. Inland from Dall Bay is a large area of banded gneiss. Farther west and north are limestone, conglomerate, schist, quartzite and greenstone. The present author noted medium-grained dioritic rock and basic and felsic dikes on the east side of Dall Bay. A sheared and brecciated zone 75 feet wide striking N. 20° E. is present on the west side of the small peninsula south of the entrance to the Bay. This zone contains angular fragments of dark fine-grained rock in a dolomite cement with some iron staining and a small amount of pyrite. The country rock is somewhat altered and slightly gneissic. Foliation trends S. 40° E. Small felsic dikes and pods of feldspar exposed along the east side of the peninsula strike N. 35° W. These are slightly radioactive.

Several copper deposits were discovered around 1900 between Dall Bay and Seal Cove, 2 miles to the north (Wright and Wright, 1908, p. 138-139; Brooks, 1902, p. 38). The prospects are in sheared and brecciated zones cutting schist and metavolcanic rocks. Pyrite and chalcopyrite are the principal metals, but minor amounts of bornite, sphalerite, gold, and silver were reported. Small tonnages of ore were shipped from the Bay View and War Eagle properties west of Seal Cove.

Williams (1956) has described the radioactive material at the Black Jack No. 7 claim at Dall Bay. The discovery reportedly was made on a very thin seam or vein of radioactive material which contained several percent uranium, but very little was found. Two small excavations were made by blasting in an effort to follow the seam, but it apparently could not be traced either laterally or in depth. Two mineralized seams were found in one pit but were only a fraction of an inch wide. The largest was on a joint or fault plane of slight displacement, and was apparently part of the "seam" from which the earlier samples were taken. The Geiger counter gave readings of 2 mr/hr at both places. Immediately adjacent to the pits in any direction brought the readings back to normal.

The country rock in the vicinity of the No. 7 discovery is a serpentinized basalt or gabbro. The serpentinized zone strikes north and dips 57° W. A 2-1/2 foot layer or sill of pink feldspar (later identified as albite) lies on the hanging wall side of the fault plane from which the radioactive material was taken. The owners reported that the same association exists at their other showings. The actual uranium mineral resembles pitchblende.

In summation, radiometric examination of the coast from one mile south of the entrance to Dall Bay to an old sawmill site at the southern extremity of Dall Bay was made in 1970 using a four-channel spectrometer. Pegmatite dikes and pods of albite on the east side of the small peninsula extending into Dall Bay produced up to 200 counts per minute against an average background of 75 counts. Feldspar pods at the Black Jack No. 7 claim on the west side of the peninsula produced up to 2,000 counts per minute. A chemical assay of the radioactive material collected in 1970 showed 80 ppm (0.008 percent) uranium. However, small hand samples of material from the area produce only a very slight amount of radioactivity. The

is reddish and coarsely crystalline. No metallic minerals were seen and the most radioactive portions of the pods appear to be associated with thin black coatings along fractures in the feldspar. No minerals other than feldspar could be recognized.

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INVESTIGATION OF ALASKA'S URANIUM POTENTIAL

Part 2

Map of the Granitic Rocks of Alaska

Regional Distribution and Tectonic Setting of Alaskan Alkaline Intrusive Igneous Rocks

By
Robert B. Forbes

SPECIAL REPORT 12

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MAP OF THE GRANITIC ROCKS OF ALASKA

Sources

The map was compiled from published and unpublished data, including U.S. and State of Alaska Geological Survey and University of Alaska sources.

Objectives

The map was compiled in an attempt to gain a better understanding of the regional tectonic setting of Alaskan granitic plutons and terranes, and the geologic controls influencing the location and distribution of various granitic rock types. Special attention was given to the occurrence of alkaline igneous rocks, and possible affinities for uranium and thorium deposits.

Explanation of Map Symbols and Rock Units

The map consists of five 1:1,000,000 sheets. Regionally important faults are shown, but no attempt has been made to differentiate fault types (e.g. normal, reverse, thrust, etc.). Where known, the granitic rocks are differentiated into the following types:

Symbol	Rock Type
gr_p	peralkaline granite
s	syenite
gn_s	gneissic syenite
a	alaskite
m	monzonite
sd	syenodiorite
gr	granite
ry	rhyolite (including hypabyssal granitic rocks)
qm	quartz monzonite
gd	granodiorite
qd	quartz diorite
di	diorite
t_j	trondjemite
gn	granitic gneiss
gru	undifferentiated granitic rocks
gn_m	migmatitic gneisses
gn_a	augen gneiss
di_c	Diorite Complex (Nabesna Dist.)
k_c	Kanektok Complex

Age of Emplacement or Recrystallization

Where known, the age of the granitic plutons is indicated by the usual prefixes (e.g. Kqd = Cretaceous quartz diorite). In some cases, the age has been determined by isotopic dating techniques...while in others, it was determined by the authors

from geologic evidence. We have attempted to be selective, and have rejected ages which appear to be arbitrarily or poorly documented.

Some of the isotopic ages must be treated as the age of recrystallization, rather than crystallization, as they apply to gneisses which are units within metamorphic terranes (e.g. Kanektok Complex, Diorite Complex).

Undifferentiated Regional Metamorphic Terranes

Gneissic rocks have been shown only if they have alkaline affinities (see next section); and we have not differentiated the regionally important migmatite and paragneiss terranes which bound the southwest flank of the Coast Range Batholith, and similar terranes which occur in the Yukon-Tanana, Maclaren, and Talkeetna Complexes.

Rock Classification

The rock classification system used for the series granite-diorite is shown in the figure below:

DESCRIPTIVE CLASSIFICATION OF IGNEOUS ROCKS

1, 2	Alkalic feldspar[3] >2/3 total feldspar	Alkalic feldspar[3] 1/3 to 2/3 total feldspar	Plagioclase 2/3 to 9/10 total feldspar	Plagioclase >9/10 total feldspar: An < 50	Plagioclase >9/10 total feldspar: An > 50	Feldspar < 10%
	Color index (CI) [illegible] 20±[4]	Color index (CI) [illegible]-40[4]			Color index (CI) 40-70[4]	Color index (CI) >70[4]
Quartz >10%	*RHYOLITE*	*DELLENITE ≡ QUARTZ LATITE*	*RHYODACITE*	*DACITE*	*QUARTZ BASALT*[5]	Extremely rare
	GRANITE CI 5-15 An 0-15	ADAMELLITE ≡ QUARTZ MONZONITE CI 10-20 An 12-33	GRANODIORITE CI 15-30 An 25-40	TONALITE ≡ QUARTZ DIORITE CI 25-40 An 35-50	QUARTZ GABBRO[5] CI 40-70 An 50-90	
	ALASKITE CI < 5 An 0-35		TRONDHJEMITE CI < 10 An 15-30			
Quartz < 10% Feldspathoids < 10%	*TRACHYTE*	*LATITE*	*ANDESITE*		*BASALT*	PERIDOTITE Pyroxene and olivine
	SYENITE CI 5-25 An 0-30	MONZONITE CI 20-35 An 25-45	DIORITE CI 25-40 An 35-50		*DIABASE (≡ DOLERITE)*	PERKNITE Pyroxene and/or amphibole
					GABBRO CI 40-70 An 50-100	DUNITE Olivine
Feldspathoids >10%	*PHONOLITE*	*FELDSPATHOIDAL LATITE*	*FELDSPATHOIDAL ANDESITE*		*FELDSPATHOIDAL BASALT*	Great variety of uncommon rocks
	FELDSPATHOIDAL SYENITE Includes many varieties of uncommon rocks	FELDSPATHOIDAL MONZONITE Rare	FELDSPATHOIDAL DIORITE Rare		FELDSPATHOIDAL AND ALKALIC GABBRO Includes many varieties of uncommon rocks	

[1] Fine grained, commonly volcanic rocks shown in italics, coarse grained, commonly plutonic rocks in gothic letters. Less common rocks of both varieties are in small print. Excepting diabase, names reflecting special textures are not shown, but some of these are defined briefly on the reverse side.
[2] Amounts of minerals based on volume percent.
[3] Includes K feldspar, perthite, and modal albite (An_0-An_{10}).
[4] Defined as the total percent of dark minerals (biotite, amphibole, pyroxene, olivine, opaque oxides, etc.)
[5] Quartz basalt and quartz gabbro may be used if quartz exceeds 2 or 3 percent.

The definition and classification of the so-called alkaline granitic rocks is a rather complex problem, and the rationale for alkaline rock classification is discussed in the following section.

REGIONAL DISTRIBUTION AND TECTONIC SETTING OF ALASKAN ALKALINE INTRUSIVE IGNEOUS ROCKS

Definitions and Classification Parameters

The classification and definition of "alkaline" igneous rocks has been plagued with many schemes and much controversy. This study cannot explore the history of this problem in depth, but the reader is referred to a most excellent treatment of the problem as recently given by Sorensen (1974).

As summarized by Sorensen (op. cit.), "the term alkaline rock has been used in at least the following meanings:

1. Igneous rocks of Atlantic or alkaline series (branch, group, facies).
2. Igneous rocks with alkali feldspar as the predominant feldspar, that is with more alkalis than average for their clans.
3. Igneous rocks containing feldspathoids.
4. Igneous rocks with an alkali-lime index less than 51 (Peacock's Alkali-lime Index).
5. Igneous rocks containing feldspathoids, and soda pyroxenes and/or amphiboles."

Shand (1922, 1933) proposed a chemical classification system which has received wide acceptance by petrologists. Shand noted that alkalis and silica are chiefly contained in feldspar, and that in alkali feldspar, the molecular ratio of $Na_2O+K_2O:Al_2O_3:SiO_2$ is 1:1:6. Muscovite contains the same components in the ratio 1:3:6.

Based on Shand's work and refinements by others, alkaline rocks can be defined by whole rock chemical compositions in which Na_2O+K_2O exceed this ratio; and such rocks can be further divided into three subgroups:

(1) Silica adequate or excessive, and alumina deficient. These rocks are composed of alkali feldspar, sodic pyroxene and/or amphibole. Quartz may also be present. Rock types include, alkali granite, pantellerite, nordmarkite.
(2) Alumina adequate or excessive, and silica deficient. Such rocks are usually composed of feldspar, feldspathoids, mica, hornblende, augite, corundum and other accessories diagnostic of silica poor-alumina rich compositions.
(3) Silica and alumina deficient. Typical minerals include feldspathoids, sodic pyroxenes and amphiboles, eudialyte, and alkali feldspars. This subgroup is dominated by the so-called "agpaitic" nepheline syenites.

Barth (1962) accepted Shand's parameters, and proposed the threefold subdivision summarized below:

(1) Ekeritic:	$Na + K < 1/6\ S_1$ $Na + K > Al$ $Ca + Mg$ low
(2) Miaskitic:	$Na + K > 1/6\ S_1$ $Na + K < Al$ K frequently $>$ Na $Ca + Mg$ as major components
(3) Agpaitic:	$Na + K > 1/6\ S_1$ $Na + K > Al$ $Na > K$ Ca, Mg low or subordinate

USSR petrologists apply the term "alkaline" to only those rocks which contain modal feldspathoids, and/or alkali amphiboles and pyroxenes. The point here is that modal enrichment of alkali feldspar does not make an alkaline rock.

Alkaline chemical parameters are also signalled by the appearance of nepheline, leucite, corundum and acmite in the molecular norm. Alkaline norm parameters are useful for the recognition of alkaline hypabyssal intrusives or volcanic rocks, which contain occult or quenched alkaline mineral phases which are not visible in outcrop or thin section.

Uranium-Thorium Affinities for Alkaline Rocks

Agpaitic nepheline syenites (and volcanic equivalents) and peralkalic granites contain higher concentrations of uranium and thorium than other igneous rocks. Sorensen (1974) has also noted that alkaline igneous rocks are richer in uranium than subalkalic relatives. Sorensen (op. cit.) also notes that "albitized and otherwise altered alkaline rocks are especially rich in uranium," and that "carbonatites may contain uranium as a constituent of pyrochlore, zirkelite, and baddeleyite." High concentrations of thorium-bearing minerals also occur in carbonatites. In our compilation and analysis of Alaskan alkaline igneous intrusive rocks, we have also considered the complementary importance of known geologic settings which increase the probability of significant uranium-thorium concentrations including:

(1) Precambrian shields or complexes.
(2) Alkaline igneous provinces, including both intrusive and extrusive rocks.
(3) Basement complexes which contain metamorphic and intrusive rocks with alkaline affinities.

Secondary Versus Primary Deposits

In another section of our report, we evaluate alkaline igneous terranes, plutons and/or complexes as possible source areas for secondary concentration in placer or replacement deposits in adjacent sedimentary basins. In the following section, however, we will discuss and evaluate the age and tectonic setting of known Alaskan alkalic rocks, and the chemical parameters which are believed to be correlated with anomalously high concentrations of uranium and thorium.

Precambrian Rocks

Currently, we know of five Alaskan areas where Precambrian rocks occur as outcrops. Three of these areas are characterized by feebly recrystallized sedimentary and volcanic rocks, in which late Precambrian ages have been documented by macrofossils and microfossils, or deduced from stratigraphic evidence, including...

(1) Tindir Group rocks (Beltian age), Nation River District, Upper Yukon River.
(2) Rocks of late Precambrian age which uncomformably underlie the Neruokpuk Formation in the eastern Brooks Range.
(3) Rocks of possible Precambrian age which underlie greenschist facies metamorphic terrane on Prince of Wales Island, southeast Alaska.
(4) A greenschist and blueschist facies basement terrane (including gneiss domes of higher metamorphic grade) extending from the Seward Peninsula to the Baird Mountains quadrangle, north of Kiana (dated at ca. 700 m.y.).
(5) The Kanektok Complex, a narrow Precambrian (dated at 1.2-1.3 b.y) belt of amphibolite facies metamorphic rocks, with associated syenitic and dioritic gneisses, northeast of Goodnews Bay.

Recent radiogenic dating has failed to confirm a Precambrian age assigned by earlier workers to many other Alaskan metamorphic terranes, including the Birch Creek Schist of the Yukon-Tanana Uplands and similar terranes in the Kokrines Hills, the northern foothills of the Alaska Range and other localities beyond the interest of this report.

Precambrian Alkaline Igneous Rocks

To date, the only documented Precambrian alkaline igneous rocks in Alaska are the gneissic syenites and related rocks of the Kanektok Complex. Although the uranium-thorium affinities of these rocks are as yet unknown, the Kanektok Complex deserves priority attention as a possible target.

Paleozoic Alkaline Igneous Rocks

Silurian Age

A 406-m.y. hornblende age was obtained by Lanphere (1964) on a syenite pluton on the east coast of Chichagof Island. Hornblende ages of 247-275 m.y. were also obtained for associated syenites and quartz diorite, indicating that this is one of two Paleozoic syenite-bearing complexes known in Alaska.

The second syenite-bearing plutonic complex associated with Silurian (Ordovician) intrusives is that of Bokan Mountain, the location of the Ross-Adams Mine, the only uranium-thorium deposit which has been mined in Alaska.

Mesozoic Alkaline Igneous Rocks

Triassic Age

Diorite Complex (Richter). This complex is composed of syenite and monzonite gneiss with intercalated layers of diorite, amphibolite and biotite schist. Some of the coarse-grained syenitic gneisses are corundum bearing. Coexisting biotite and hornblende from a pegmatitic phase of syenite gneiss gave concordant K-Ar ages of 198 and 199 m.y. Although the alkalic nature of this complex is certain, no anomalous concentrations of uranium or thorium have been reported, even though the area has been rather extensively prospected and surveyed.

The pink orthoclase gneisses in the Diorite Complex are remarkably similar to those in the Kanektok Complex.

Mid-Cretaceous Age

Alkaline intrusive rocks of mid-Cretaceous age (Miller, 1972) occur in a 750-km-long belt of small plutons that extends from the Zane Hills in central Alaska to St. Lawrence Island, in the Bering Sea. These small plutons are known to contain anomalous concentrations of radioactive elements, particularly thorium, and have been subjected to uranium and thorium analysis by various workers in recent years (Miller and Bunker, 1975a, b; Forbes and Jones, unpub. manuscript). The following are brief descriptions of these plutons as described by Miller (1972), Miller and others (1972), and Csejtey and Patton (1974).

Selawik Lake Complex

The Selawik Lake Complex is a small (18 sq km) alkaline pluton located on the south shore of Selawik Lake in western Alaska. The northern half of the complex is composed of massive leucocratic juvite (Miller, 1972). Melanite garnet is abundant, constituting as much as 15 percent of the rock. The southern half of the pluton is poorly exposed and consists of perthosite and malignite.

Hunt Complex

The Hunt Complex is exposed over a 13-sq-km area on the north side of the Selawik Hills. It is chiefly composed of malignite and foyaite, cut by abundant red trachyte porphyry dikes. The stock intrudes andesitic country rocks.

Inland Lake Complex

This alkaline stock covers an area of 30 sq miles on the south side of Inland Lake in the Kobuk-Selawik Lowlands. It is composed of pulaskite in the northern part, and malignite and foyaite in the southern part.

Ekiek Creek Complex

The Ekiek Creek Complex is composed of a wide variety of alkaline rock types. Malignite and pyroxenite, cut by foyaite and juvite dikes, are the predominant rock types on the north margin of the pluton. The southern part is chiefly composed of borolanite with mafic septa(?) of wallrock, and minor pyroxenite and ijolite.

Granite Mountain

The Granite Mountain stock, located on the eastern edge of the Seward Peninsula, is a zoned alkalic-alkaline pluton about 70 sq km. Miller (1972) described the stock as a concentrically zoned complex, with the core composed of equigranular quartz monzonite, an inner crescent-shaped zone of massive to porphyritic monzonite partly surrounding the quartz monzonite, and an outer crescent-shaped zone of foyaite and garnet-bearing syenite. A systematic sampling traverse across Granite Mountain conducted by Forbes and Jones (unpub. manuscript) suggests that the zoning in the pluton may be more complex than was originally believed.

Dry Canyon Stock

The Dry Canyon stock, located on the west side of the Darby pluton on the eastern Seward Peninsula, is composed of leucocratic porphyritic to trachytoid foyaite (Miller and others, 1972). The stock is cut by blue-gray pulaskite dikes and, on the basis of a K-Ar age of 105 $\pm$ 3 m.y. (M.A. Lanphere, written communication in Miller and others, 1972), has been tentatively assigned a mid-Cretaceous age.

Windy Creek Pluton

Boulders of melanite-hornblende foyaite are found in gravels of streams draining the east side of the Windy Creek pluton east of the Darby Mountains on the Seward Peninsula. The major rock types in the pluton are quartz monzonite and monzonite. Although the nepheline syenite has not been found in outcrops,

lithologic similarities suggest that the Windy Creek pluton may be a zoned complex similar to Granite Mountain (Miller, 1972).

Alkaline Dikes on the Southeastern Seward Peninsula

Pulaskite, pseudoleucite porphyry, and foyaite dike rocks crop out over an area of about 260 sq km in the Kachauik pluton and adjacent metamorphic terrane in the southeastern Seward Peninsula (Miller, 1972). Miller notes that although the area has been mapped only in reconnaissance, alkaline dikes were found at almost every locality examined. The major minerals in the dikes are nepheline, alkali feldspar, pseudoleucite, melanite-garnet, and fluorite.

Alkaline Dikes in the Selawik Hills

Dikes of foyaite and borolanite intrude syenite and contact metamorphic rocks in the northwestern Selawik Hills (Miller, 1972). Alkaline dikes were found at eight localities within an area of about 25 sq km, but the pluton has been mapped only in reconnaissance and more of these same dikes are probably present (Miller, op. cit.).

Nepheline Syenite of St. Lawrence Island

Approximately 44 sq km of nepheline syenite rubble crop is located on the east side of Koozata Lagoon, on St. Lawrence Island (Csejtey and Patton, 1974). The major minerals include potassium feldspar, nepheline, biotite, and melanite garnet. Sodic andesine, hornblende, and purple fluorite are present in minor amounts. Accessory minerals include sphene, magnetite, zircon, apatite, allanite and sparse calcite (Csejtey and Patton, op. cit.).

Zane Hills Alkalic Plutons

Two small bodies of porphyritic to gneissic monzonite occur along the south and east margin of the Zane Hills pluton in central Alaska (Miller, 1970). Although the monzonite contains minor amounts of quartz, a chemical analysis of the rock (in Miller, 1970) indicates that the monzonite is in fact an alkaline rock according to Shand's classification. The rock contains an amphibole with a sea-green component to its pleochroic scheme, suggesting a high alkali content.

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INDEX OF ALASKAN "ALKALINE" IGNEOUS ROCKS AS DETERMINED FROM NORM CALCULATIONS

(Ne, Le, Co, Ac)

<u>Atlin Quadrangle</u>

26. Alaskite

<u>Candle Quadrangle</u>

36. Garnet syenite
37. Garnet syenite
38. Pseudoleucite porphyry
39. Foyaite
40. Foyaite
44. Monzonite

<u>Craig Quadrangle</u>

12. Diorite
14. Calcite syenite
15. Monzonite
23. Calcite syenite
24. Monzonite

<u>Dixon Entrance Quadrangle</u>

28. Syenite
29. Syenite
30. Granite
31. Granite
32. Granite
33. Granite
34. Granite

<u>Fairbanks Quadrangle</u>

01. Granite

<u>Hughes Quadrangle</u>

07. Dacite
35. Monzonite

<u>Iditarod Quadrangle</u>

05. Monzonite

<u>Juneau Quadrangle</u>

19. Albite diorite
20. Diorite
21. Albite diorite
22. Soda syenite

<u>Saint Lawrence Quadrangle</u>

80. Nepheline syenite
81. Nepheline syenite
82. Nepheline syenite
83. Nepheline syenite

<u>Selawik Quadrangle</u>

45. Biotite pyroxenite
46. Ijolite
47. Malignite
48. Malignite
49. Malignite
50. Shonkinite
51. Malignite
52. Borolanite
53. Trachyte
54. Juvite
55. Foyaite
56. Pulaskite
57. Juvite
58. Foyaite
59. Pulaskite
62. Monzonite
69. Trachyte
70. Trachyte
72. Monzonite
74. Trachytoid foyaite
78. Pulaskite
79. Lamprophyre

<u>Tanacross Quadrangle</u>

89. Syenite

<u>Tanana Quadrangle</u>

02. Monzonite

INDEX OF ALASKAN "ALKALINE" IGNEOUS ROCKS AS DETERMINED FROM NORM CALCULATIONS (Cont.)

(Ne, Le, Co, Ac)

Taylor Mountains Quadrangle

06. Biotite granite

Teller Quadrangle

84. Granite
85. Granite
86. Granite
87. Granite
88. Granite

KEY FOR ROCK-TYPE SYMBOLS USED IN NORM PRINTOUTS

AD = Albite Diorite
AK = Alaskite
BG = Biotite Granite
BP = Biotite Pyroxenite
BR = Borolanite
CS = Calcite Syenite
DA = Dacite
DI = Diorite
DO = Diopside Orthoclasite
FY = Foyaite
GD = Granodiorite
GR = Granite
GS = Garnet Syenite
IJ = Ijolite
JF = Juvite

LM = Lamprophyre
MD = Monzodiorite
MG = Malignite
MZ = Monzonite
LP = Pseudoleucite Porphyry
NS = Nepheline Syenite
OR = Orthoclasite
00 = Rock type not given
PK = Pulaskite
SH = Shonkinite
SS = Soda Syenite
SY = Syenite
TF = Trachytoid Foyaite
TR = Trachyte
TS = Trachyte

ATLIN QUADRANGLE

ALAK25	1	0						
SIO2=	76.30	77.06	QZ=	33.66	DI=	0.0		
TIO2=	0.05	0.06	OR=	28.15	HY=	0.0	(EN= 0.0	FS= 0.0)
AL2O3=	12.50	12.63	AB=	35.37	OL=	0.0	(FO= 0.0	FA= 0.0)
FE2O3=	1.47	1.49	AN=	0.86	MT=	0.0		
FEO=	0.0	0.00	NE=	0.0	IL=	0.0		
MNO=	0.0	0.00			AP=	0.0		
MGO=	0.0	0.00	LE=	0.0				
CAO=	0.17	0.18	CC=	0.88	CC=	0.0		
NA2O=	3.86	3.90	KS=	0.0	HT=	1.05		
K2O=	4.67	4.72	NS=	0.0	WO=	0.0		
P2O5=	0.0	0.00	CS=	0.0	TN=	0.0		
H2O+=	0.32				RU=	0.04		
H2O-=	0.18				AC=	0.0		
CR2O3=	0.0	0.00						
NIO=	0.0	0.00						
CO2=	0.0							
TOTALS	99.52	100.01		98.92		1.08		

RATIOS PL= 2.38 EN= 0.0 OL= 0.0

CANDLE QUADRANGLE

CDGS36	1	0						
SIO2=	55.40	56.40	QZ=	0.0	DI=	2.87		
TIO2=	0.59	0.61	OR=	38.24	HY=	0.0	(EN= 0.0	FS= 0.0)
AL2O3=	19.00	19.35	AB=	29.44	OL=	2.93	(FO= 2.93	FA= 0.0)
FE2O3=	4.10	4.18	AN=	14.70	MT=	4.26		
FEO=	2.20	2.24	NE=	4.67	IL=	0.83		
MNO=	0.14	0.15			AP=	0.44		
MGO=	1.40	1.43	LE=	0.0				
CAO=	4.70	4.79	CC=	0.0	CC=	0.13		
NA2O=	4.10	4.18	KS=	0.0	HT=	0.05		
K2O=	6.40	6.52	NS=	0.0	WO=	0.0		
P2O5=	0.21	0.22	CS=	0.0	TN=	0.0		
H2O+=	1.50				RU=	0.0		
H2O-=	0.20				AC=	0.0		
CR2O3=	0.0	0.00						
NIO=	0.0	0.00						
CO2=	0.05							
TOTALS	99.99	100.01		87.05		11.51		

RATIOS PL= 33.31 EN= 0.0 OL= 100.00

CDGS37 1 0

SIO2=	53.70	54.26	QZ=	0.0	DI=	6.09			
TIO2=	0.73	0.74	OR=	25.03	HY=	0.0	(EN=	0.0	FS=
AL2O3=	17.80	17.99	AB=	30.97	OL=	6.27	(FO=	5.64	FA=
FE2O3=	4.80	4.85	AN=	18.38	MT=	5.06			
FEO=	3.20	3.24	NE=	3.16	IL=	1.03			
MNO=	0.15	0.16			AP=	0.84			
MGO=	2.70	2.73	LE=	0.0					
CAO=	7.30	7.38	CC=	0.0	CC=	0.13			
NA2O=	4.00	4.05	KS=	0.0	HT=	0.0			
K2O=	4.20	4.25	NS=	0.0	WC=	0.0			
P2O5=	0.40	0.41	CS=	0.0	TN=	0.0			
H2O+=	0.75				RU=	0.0			
H2O-=	0.20				AC=	0.0			
CR2O3=	0.0	0.00							
NIO=	0.0	0.00							
CO2=	0.05								
TOTALS	99.98	100.01		77.54		19.42			

RATIOS PL= 37.24 EN= 0.0 OL= 89.98

CCLP38 1 0

SIO2=	50.00	50.91	QZ=	0.0	DI=	21.07			
TIO2=	0.90	0.92	OR=	35.53	HY=	0.0	(EN=	0.0	FS=
AL2O3=	17.40	17.72	AB=	4.97	OL=	0.0	(FO=	0.0	FA=
FE2O3=	4.10	4.18	AN=	16.91	MT=	4.37			
FEO=	3.80	3.87	NE=	13.49	IL=	1.28			
MNO=	0.18	0.19			AP=	1.15			
MGO=	2.80	2.86	LE=	0.0					
CAO=	9.60	9.78	CO=	0.0	CC=	0.13			
NA2O=	3.00	3.06	KS=	0.0	HT=	0.0			
K2O=	5.90	6.01	NS=	0.0	WC=	1.11			
P2O5=	0.54	0.55	CS=	0.0	TN=	0.0			
H2O+=	1.40				RU=	0.0			
H2O-=	0.19				AC=	0.0			
CR2O3=	0.0	0.00							
NIO=	0.0	0.00							
CO2=	0.05								
TOTALS	99.86	100.01		70.90		29.10			

RATIOS PL= 77.30 EN= 0.0 OL= 0.0

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CDFY39        1      0
     SIO2=   55.50  56.49    QZ=   0.0    DI=   4.07
     TIO2=    0.65   0.67    OR=  41.09   HY=   0.0     (EN=   0.0     FS=   0.0 )
     AL2O3=  19.30  19.65    AB=  21.39   OL=   4.55    (FO=   3.13    FA=   1.42)
     FE2O3=   2.10   2.14    AN=  15.80   MT=   2.21
     FEO=     2.60   2.65    NE=   7.26   IL=   0.91
     MNO=     0.14   0.15                 AP=   0.55
     MGO=     1.50   1.53    LE=   0.0
     CAO=     5.60   5.70    CO=   0.0    CC=   0.13
     NA2O=    3.70   3.77    KS=   0.0    HT=   0.0
     K2O=     6.90   7.03    NS=   0.0    WO=   0.0
     P2O5=    0.26   0.27    CS=   0.0    TN=   0.0
     H2O+=    1.50                        RU=   0.0
     H2O-=    0.20                        AC=   0.0
     CR2O3=   0.0    0.00
     NIO=     0.0    0.00
     CO2=     0.05
    TOTALS  100.00 100.01         85.54        12.42

       RATIOS      PL=   42.49     EN=    0.0      OL=   68.80


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     TIO2=    0.62   0.64    OR=  44.03   HY=   0.0     (EN=   0.0     FS=   0.0 )
     AL2O3=  19.40  19.73    AB=  19.83   OL=   3.10    (FO=   2.50    FA=   0.60)
     FE2O3=   2.80   2.85    AN=  14.13   MT=   2.95
     FEO=     2.20   2.24    NE=   8.72   IL=   0.87
     MNO=     0.13   0.14                 AP=   0.44
     MGO=     1.20   1.23    LE=   0.0
     CAO=     5.10   5.19    CO=   0.0    CC=   0.13
     NA2O=    3.80   3.87    KS=   0.0    HT=   0.0
     K2O=     7.40   7.53    NS=   0.0    WO=   0.0
     P2O5=    0.21   0.22    CS=   0.0    TN=   0.0
     H2O+=    1.50                        RU=   0.0
     H2O-=    0.21                        AC=   0.0
     CR2O3=   0.0    0.00
     NIO=     0.0    0.00
     CO2=     0.05
    TOTALS  100.12 100.01         86.71        11.36

       RATIOS      PL=   41.60     EN=    0.0      OL=   80.61
```

CDMZ44	1	C						
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FE2O3=	0.80	0.81	AN=	10.94	MT=	0.84		
FEO=	1.00	1.01	NE=	0.0	IL=	0.35		
MNO=	0.05	0.06			AP=	0.21		
MGO=	0.52	0.53	LE=	0.0				
CAO=	2.40	2.42	CO=	0.95√	CC=	0.13		
NA2O=	4.80	4.84	KS=	0.0	HT=	0.0		
K2O=	4.00	4.04	NS=	0.0	WO=	0.0		
P2O5=	0.10	0.11	CS=	0.0	TN=	0.0		
H2O+=	0.50				RU=	0.0		
H2O-=	0.11				AC=	0.0		
CR2O3=	0.0	0.00						
NIO=	0.0	0.00						
CO2=	0.05							
TOTALS	99.88	100.01		96.32		3.68		

RATIOS PL= 20.24 EN= 66.55 OL= 0.0

CRAIG QUADRANGLE

CGDI12	1	C						
SIO2=	59.44	62.78	QZ=	16.74	DI=	0.0		
TIO2=	0.66	0.70	CR=	19.49	HY=	6.70	(EN= 5.28	FS= 1.42)
AL2O3=	17.40	18.38	AB=	40.07	OL=	0.0	(FO= 0.0	FA= 0.0)
FE2O3=	3.30	3.49	AN=	5.99	MT=	3.65		
FEO=	2.77	2.93	NE=	0.0	IL=	0.97		
MNO=	0.17	0.18			AP=	0.62		
MGO=	1.81	1.92	LE=	0.0				
CAO=	1.51	1.60	CO=	5.78√	CC=	0.0		
NA2O=	4.22	4.46	KS=	0.0	HT=	0.0		
K2O=	3.12	3.30	NS=	0.0	WO=	0.0		
P2O5=	0.28	0.30	CS=	0.0	TN=	0.0		
H2O+=	0.56				RU=	0.0		
H2O-=	0.06				AC=	0.0		
CR2O3=	0.0	0.00						
NIO=	0.0	0.00						
CO2=	0.0							
TOTALS	95.30	100.01		88.06		11.94		

RATIOS PL= 13.00 EN= 78.88 OL= 0.0

```
CGCS14        1      0
     SIO2=    63.41   66.31      QZ= 10.06    DI=   0.0
     TIO2=    0.26    0.28       OR= 17.93    HY=   4.46   (EN=  0.0      FS=  4.46)
     AL2O3=   16.06   17.64      AB= 65.07    OL=   0.0    (FO=  0.0      FA=  0.0 )
     FE2O3=   0.0     0.00       AN=-11.03    MT=   0.0
     FEO=     2.88    3.02       NE=  0.0     IL=   0.36
     MNO=     0.28    0.30                    AP=   0.0
     MGO=     0.0     0.00       LE=  0.0
     CAO=     1.47    1.54       CO=  5.89✓   CC=   7.28
     NA2O=    7.38    7.72       KS=  0.0     HT=   0.0
     K2O=     3.09    3.24       NS=  0.0     WO=   0.0
     P2O5=    0.0     0.00       CS=  0.0     TN=   0.0
     H2O+=    0.42                            RU=   0.0
     H2O-=    0.29                            AC=   0.0
     CR2O3=   0.0     0.00
     NIO=     0.0     0.00
     CO2=     2.93
   TOTALS     99.27  100.01          87.91          12.09

     RATIOS        PL= -20.41     EN=    0.0       OL=    0.0
```

```
CGMZ15        1      0
     SIO2=    58.87   59.76      QZ=  0.0     DI= 12.73
     TIO2=    0.59    0.60       OR= 25.43    HY=   0.0    (EN=  0.0      FS=  0.0 )
     AL2O3=   17.12   17.38      AB= 39.65    OL=   0.0    (FO=  0.0      FA=  0.0 )
     FE2O3=   1.96    1.99       AN= 12.96    MT=   1.20
     FEO=     0.95    0.97       NE=  1.00✓   IL=   0.82
     MNO=     0.10    0.11                    AP=   0.41
     MGO=     1.75    1.78       LE=  0.0
     CAO=     8.00    8.13       CO=  0.0     CC=   2.11
     NA2O=    4.64    4.71       KS=  0.0     HT=   0.55
     K2O=     4.34    4.41       NS=  0.0     WO=   3.14
     P2O5=    0.20    0.21       CS=  0.0     TN=   0.0
     H2O+=    0.81                            RU=   0.0
     H2O-=    0.13                            AC=   0.0
     CR2O3=   0.0     0.00
     NIO=     0.0     0.00
     CO2=     0.84
   TOTALS    100.30  100.01          79.04          20.96

     RATIOS        PL=  24.64     EN=    0.0       OL=    0.0
```

```
CGCS23      1     C
    SIO2=  63.41  66.23     QZ= 10.36    DI=  0.0
    TIO2=   0.26   0.28     OR= 17.91    HY=  4.45    (EN=  0.0     FS=  4.45)
    AL2O3= 16.86  17.61     AB= 65.01    OL=  0.0     (FO=  0.0     FA=  0.0 )
    FE2O3=  0.0    0.00     AN=-11.79    MT=  0.0
    FEO=    2.88   3.01     NE=  0.0     IL=  0.36
    MNO=    0.28   0.30                  AP=  0.25
    MGO=    0.0    0.00     LE=  0.0
    CAO=    1.47   1.54     CO=  6.19    CC=  7.27
    NA2O=   7.38   7.71     KS=  0.0     HT=  0.0
    K2O=    3.09   3.23     NS=  0.0     WO=  0.0
    P2O5=   0.12   0.13     CS=  0.0     TN=  0.0
    H2O+=   0.42                         RU=  0.0
    H2O-=   0.29                         AC=  0.0
    CR2O3=  0.0    0.00
    NIO=    0.0    0.00
    CO2=    2.93
   TOTALS  99.39 100.01         87.68        12.32

     RATIOS      PL= -22.15    EN=   0.0      OL=   0.0
```

```
CGMZ24      1     C
    SIO2=  58.87  59.76     QZ=  0.0     DI= 12.73
    TIO2=   0.59   0.60     OR= 25.43    HY=  0.0     (EN=  0.0     FS=  0.0 )
    AL2O3= 17.12  17.38     AB= 39.65    OL=  0.0     (FO=  0.0     FA=  0.0 )
    FE2O3=  1.96   1.99     AN= 12.96    MT=  1.20
    FEO=    0.95   0.97     NE=  1.00    IL=  0.82
    MNO=    0.10   0.11                  AP=  0.41
    MGO=    1.75   1.78     LE=  0.0
    CAO=    8.00   8.13     CO=  0.0     CC=  2.11
    NA2O=   4.64   4.71     KS=  0.0     HT=  0.55
    K2O=    4.34   4.41     NS=  0.0     WO=  3.14
    P2O5=   0.20   0.21     CS=  0.0     TN=  0.0
    H2O+=   0.81                         RU=  0.0
    H2O-=   0.13                         AC=  0.0
    CR2O3=  0.0    0.00
    NIO=    0.0    0.00
    CO2=    0.84
   TOTALS 100.30 100.01         79.04        20.96

     RATIOS      PL=  24.64    EN=   0.0      OL=   0.0
```

DXSY28 1 0

SIO2=	63.10	64.11	QZ=	2.78	DI=	0.0	
TIO2=	0.44	0.45	OR=	38.92	HY=	2.37	(EN= 1.76 FS= 0.61)
AL2O3=	17.90	18.19	AB=	50.33	CL=	0.0	(FO= 0.0 FA= 0.0)
FE2O3=	1.30	1.33	AN=	-0.13	MT=	1.34	
FEO=	1.30	1.33	NE=	0.0	IL=	0.60	
MNO=	0.08	0.09			AP=	0.12	
MGO=	0.65	0.67	LE=	0.0			
CAO=	1.20	1.22	CO=	1.42✓	CC=	2.24	
NA2O=	5.70	5.80	KS=	0.0	HT=	0.0	
K2O=	6.70	6.81	NS=	0.0	WC=	0.0	
P2O5=	0.06	0.07	CS=	0.0	TN=	0.0	
H2O+=	0.58				RU=	0.0	
H2O-=	0.0				AC=	0.0	
CR2O3=	0.0	0.00					
NIO=	0.0	0.00					
CO2=	0.90						
TOTALS	99.91	100.01		93.32		6.68	

RATIOS PL= -0.25 EN= 74.31 OL= 0.0

DXSY29 1 0

SIO2=	62.10	64.08	QZ=	4.54	DI=	0.0	
TIO2=	0.16	0.17	OR=	30.91	HY=	2.20	(EN= 1.14 FS= 1.05)
AL2O3=	18.90	19.51	AB=	55.83	CL=	0.0	(FO= 0.0 FA= 0.0)
FE2O3=	1.00	1.04	AN=	-2.27	MT=	1.03	
FEO=	1.20	1.24	NE=	0.0	IL=	0.22	
MNO=	0.08	0.09			AP=	0.12	
MGO=	0.42	0.44	LE=	0.0			
CAO=	1.40	1.45	CO=	3.92✓	CC=	3.49	
NA2O=	6.30	6.51	KS=	0.0	HT=	0.0	
K2O=	5.30	5.47	NS=	0.0	WC=	0.0	
P2O5=	0.06	0.07	CS=	0.0	TN=	0.0	
H2O+=	0.54				RU=	0.0	
H2O-=	0.0				AC=	0.0	
CR2O3=	0.0	0.00					
NIO=	0.0	0.00					
CO2=	1.40						
TOTALS	98.86	100.01		92.93		7.07	

RATIOS PL= -4.23 EN= 52.14 OL= 0.0

DXGR30 1 C

SIO2=	73.40	73.96	QZ=	29.21	DI=	0.0		
TIO2=	0.20	0.21	OR=	27.72	HY=	1.76	(EN= 0.14	FS= 1.62)
AL2O3=	11.00	11.09	AB=	33.52	OL=	0.0	(FO= 0.0	FA= 0.0)
FE2O3=	3.60	3.63	AN=	-1.42	MT=	1.53		
FEO=	1.80	1.82	NE=	0.0	IL=	0.28		
MNO=	0.05	0.06			AP=	0.0		
MGO=	0.05	0.06	LE=	0.0				
CAO=	0.05	0.06	CO=	0.57	CC=	0.67		
NA2O=	4.50	4.54	KS=	0.0	HT=	0.0		
K2O=	4.60	4.64	NS=	0.0	WO=	0.0		
P2O5=	0.0	0.00	CS=	0.0	TN=	0.0		
H2O+=	0.35				RU=	0.0		
H2O-=	0.0				AC=	6.15		
CR2O3=	0.0	0.00						
NIO=	0.0	0.00						
CO2=	0.26							
TOTALS	99.86	100.01		89.60		10.40		

RATIOS PL= -4.44 EN= 8.00 OL= 0.0

DXGR31 1 C

SIO2=	74.10	74.31	QZ=	26.20	DI=	0.0		
TIO2=	0.15	0.16	OR=	27.91	HY=	2.87	(EN= 0.14	FS= 2.73)
AL2O3=	12.30	12.34	AB=	39.57	OL=	0.0	(FO= 0.0	FA= 0.0)
FE2O3=	1.50	1.51	AN=	-1.59	MT=	0.45		
FEO=	2.00	2.01	NE=	0.0	IL=	0.21		
MNO=	0.08	0.09			AP=	0.0		
MGO=	0.05	0.06	LE=	0.0				
CAO=	0.05	0.06	CO=	0.64	CC=	0.74		
NA2O=	4.80	4.82	KS=	0.0	HT=	0.0		
K2O=	4.70	4.72	NS=	0.0	WO=	0.0		
P2O5=	0.0	0.00	CS=	0.0	TN=	0.0		
H2O+=	0.38				RU=	0.0		
H2O-=	0.0				AC=	3.00		
CR2O3=	0.0	0.00						
NIO=	0.0	0.00						
CO2=	0.29							
TOTALS	100.40	100.01		92.73		7.27		

RATIOS PL= -4.20 EN= 4.84 OL= 0.0

DXGR32 1 0

SIO2=	73.60	73.95	QZ=	26.12	DI=	0.0		
TIO2=	0.14	0.15	OR=	26.86	HY=	4.00	(EN= 0.14	FS= 3.86)
AL2O3=	11.60	11.66	AB=	37.11	OL=	0.0	(FO= 0.0	FA= 0.0)
FE2O3=	2.10	2.11	AN=	-1.41	MT=	0.02		
FEO=	2.50	2.52	NE=	0.0	IL=	0.20		
MNO=	0.10	0.11			AP=	0.0		
MGO=	0.05	0.06	LE=	0.0				
CAO=	0.05	0.06	CO=	0.56	CC=	0.66		
NA2O=	4.90	4.93	KS=	0.0	HT=	0.0		
K2O=	4.50	4.53	NS=	0.0	WO=	0.0		
P2O5=	0.0	0.00	CS=	0.0	TN=	0.0		
H2O+=	0.32				RU=	0.0		
H2O-=	0.0				AC=	5.87		
CR2O3=	0.0	0.00						
NIO=	0.0	0.00						
CO2=	0.26							
TOTALS	100.12	100.01		89.25		10.75		

RATIOS PL= -3.95 EN= 3.48 OL= 0.0

DXGR33 1 0

SIO2=	74.60	74.76	QZ=	26.70	DI=	0.39		
TIO2=	0.12	0.13	OR=	24.44	HY=	3.96	(EN= 0.25	FS= 3.71)
AL2O3=	11.90	11.93	AB=	41.09	OL=	0.0	(FO= 0.0	FA= 0.0)
FE2O3=	1.20	1.21	AN=	0.0	MT=	0.28		
FEO=	2.50	2.51	NE=	0.0	IL=	0.17		
MNO=	0.10	0.11			AP=	0.02		
MGO=	0.09	0.10	LE=	0.0				
CAO=	0.27	0.28	CO=	0.0	CC=	0.13		
NA2O=	4.90	4.92	KS=	0.0	HT=	0.0		
K2O=	4.10	4.11	NS=	0.0	WO=	0.0		
P2O5=	0.01	0.02	CS=	0.0	TN=	0.0		
H2O+=	0.46				RU=	0.0		
H2O-=	0.0				AC=	2.64		
CR2O3=	0.0	0.00						
NIO=	0.0	0.00						
CO2=	0.05							
TOTALS	100.30	100.01		92.23		7.58		

RATIOS PL= 0.0 EN= 6.33 OL= 0.0

DXGR34	1	0						
SIO2=	73.80	73.78	QZ=	26.18	DI=	0.15		
TIO2=	0.12	0.12	CR=	25.05	HY=	3.69	(EN= 0.22	FS= 3.47)
AL2O3=	11.50	11.50	AB=	38.31	OL=	0.0	(FO= 0.0	FA= 0.0)
FE2O3=	2.60	2.60	AN=	0.0	MT=	0.64		
FEO=	2.50	2.50	NE=	0.0	IL=	0.17		
MNO=	0.10	0.10			AP=	0.0		
MGO=	0.08	0.08	LE=	0.0				
CAO=	0.14	0.14	CO=	0.0	CC=	0.13		
NA2O=	5.00	5.00	KS=	0.0	HT=	0.0		
K2O=	4.20	4.20	NS=	0.0	WO=	0.0		
P2O5=	0.0	0.00	CS=	0.0	TN=	0.0		
H2O+=	0.31				RU=	0.0		
H2O-=	0.0				AC=	5.60		
CR2O3=	0.0	0.00						
NIO=	0.0	0.00						
CO2=	0.05							
TOTALS	100.40	100.01		89.54		10.39		

RATIOS PL= 0.0 EN= 6.04 OL= 0.0

FAIRBANKS QUADRANGLE

FXGR01	1	0						
SIO2=	78.47	77.90	QZ=	33.10	DI=	1.71		
TIO2=	0.01	0.01	OR=	28.37	HY=	3.03	(EN= 2.38	FS= 0.65)
AL2O3=	10.94	10.86	AB=	31.49	OL=	0.0	(FO= 0.0	FA= 0.0)
FE2O3=	0.63	0.63	AN=	0.0	MT=	0.20		
FEO=	0.48	0.48	NE=	0.0	IL=	0.01		
MNO=	0.03	0.03			AP=	0.0		
MGO=	0.86	0.86	LE=	0.0				
CAO=	0.86	0.86	CO=	0.0	CC=	0.0		
NA2O=	3.67	3.65	KS=	0.0	HT=	0.0		
K2O=	4.79	4.76	NS=	0.0	WO=	0.0		
P2O5=	0.0	0.00	CS=	0.0	TN=	0.0		
H2O+=	0.09				RU=	0.0		
H2O-=	0.01				AC=	1.23		
CR2O3=	0.0	0.00						
NIO=	0.0	0.00						
CO2=	0.0							
TOTALS	100.84	100.01		92.96		6.13		

RATIOS PL= 0.0 EN= 78.63 OL= 0.0

HUGHES QUADRANGLE

HUDA07 1 0

SIO2=	67.20	70.28	QZ= 27.89	DI=	0.0		
TIO2=	0.29	0.31	OR= 11.15	HY=	4.03	(EN= 3.76	FS= 0.27)
AL2O3=	15.20	15.90	AB= 36.72	OL=	0.0	(FO= 0.0	FA= 0.0)
FE2O3=	1.30	1.36	AN= 16.59	MT=	1.43		
FEO=	0.96	1.01	NE= 0.0	IL=	0.42		
MNO=	0.05	0.06		AP=	0.26		
MGO=	1.30	1.36	LE= 0.0				
CAO=	3.50	3.67	CO= 1.19	CC=	0.32		
NA2O=	3.90	4.08	KS= 0.0	HT=	0.0		
K2O=	1.80	1.89	NS= 0.0	WO=	0.0		
P2O5=	0.12	0.13	CS= 0.0	TN=	0.0		
H2O+=	2.20			RU=	0.0		
H2O-=	0.66			AC=	0.0		
CR2O3=	0.0	0.00					
NIO=	0.0	0.00					
CO2=	0.12						
TOTALS	98.60	100.01	93.54		6.46		

RATIOS PL= 31.12 EN= 93.35 OL= 0.0

HUMZ35 1 0

SIO2=	61.10	61.57	QZ= 0.0	DI=	1.22		
TIO2=	0.39	0.40	OR= 36.79	HY=	0.0	(EN= 0.0	FS= 0.0)
AL2O3=	19.00	19.15	AB= 46.81	OL=	2.34	(FO= 1.70	FA= 0.64)
FE2O3=	1.70	1.72	AN= 9.34	MT=	1.76		
FEO=	1.60	1.62	NE= 0.14	IL=	0.54		
MNO=	0.07	0.08		AP=	0.33		
MGO=	0.83	0.84	LE= 0.0				
CAO=	2.80	2.83	CO= 0.0	CC=	0.13		
NA2O=	5.30	5.35	KS= 0.0	HT=	0.0		
K2O=	6.30	6.35	NS= 0.0	WO=	0.0		
P2O5=	0.16	0.17	CS= 0.0	TN=	0.0		
H2O+=	0.67			RU=	0.0		
H2O-=	0.06			AC=	0.0		
CR2O3=	0.0	0.00					
NIO=	0.0	0.00					
CO2=	0.05						
TOTALS	100.03	100.01	93.09		6.31		

RATIOS PL= 16.63 EN= 0.0 OL= 72.71

IDITAROD QUADRANGLE

IDMZ05 1 C

SIO2=	57.16	57.81	QZ=	0.0	DI=	4.01		
TIO2=	0.30	0.31	OR=	30.99	HY=	0.0	(EN= 0.0	FS= 0.0)
AL2O3=	16.38	17.07	AB=	31.11	OL=	15.55	(FO= 9.76	FA= 5.79)
FE2O3=	0.26	0.27	AN=	9.25	MT=	0.27		
FEO=	5.36	5.43	NE=	6.14	IL=	0.41		
MNO=	0.03	0.09			AP=	0.0		
MGO=	4.78	4.84	LE=	0.0				
CAO=	4.08	4.13	CO=	0.0	CC=	0.27		
NA2O=	4.67	4.73	KS=	0.0	HT=	0.0		
K2O=	5.32	5.38	NS=	0.0	WO=	0.0		
P2O5=	0.0	0.00	CS=	0.0	TN=	0.0		
H2O+=	0.69				RU=	0.0		
H2O-=	0.04				AC=	0.0		
CR2O3=	0.0	0.00						
NIO=	0.0	0.00						
CO2=	0.11							
TOTALS	99.73	100.01		77.49		20.51		

RATIOS PL= 22.93 EN= 0.0 OL= 62.77

JUNEAU QUADRANGLE

JUAD19 1 0

SIO2=	64.36	66.60	QZ=	6.72	DI=	0.0		
TIO2=	0.17	0.18	OR=	5.12	HY=	0.91	(EN= 0.75	FS= 0.15)
AL2O3=	18.18	18.82	AB=	78.41	OL=	0.0	(FO= 0.0	FA= 0.0)
FE2O3=	0.64	0.67	AN=	2.02	MT=	0.65		
FEO=	0.43	0.45	NE=	0.0	IL=	0.23		
MNO=	0.11	0.12			AP=	0.12		
MGO=	0.28	0.29	LE=	0.0				
CAO=	2.56	2.65	CO=	1.83	CC=	3.99		
NA2O=	8.96	9.28	KS=	0.0	HT=	0.0		
K2O=	0.89	0.93	NS=	0.0	WO=	0.0		
P2O5=	0.06	0.07	CS=	0.0	TN=	0.0		
H2O+=	0.55				RU=	0.0		
H2O-=	0.18				AC=	0.0		
CR2O3=	0.0	0.00						
NIO=	0.0	0.00						
CO2=	1.62							
TOTALS	98.99	100.01		94.10		5.90		

RATIOS PL= 2.51 EN= 83.22 OL= 0.0

```
JUDI20       1     0
    SIO2=   44.69   50.75      QZ=  15.67    DI=   0.0
    TIO2=    2.25    2.56      OR=  10.62    HY=  18.80   (EN= 11.05    FS=  7.75)
    AL2O3=  14.97   17.00      AB=  21.64    OL=   0.0    (FO=  0.0     FA=  0.0 )
    FE2O3=   0.60    0.69      AN=  -5.40    MT=   0.64
    FEO=     7.05    8.01      NE=   0.0     IL=   3.20
    MNO=     0.14    0.16                    AP=   0.56
    MGO=     3.92    4.46      LE=   0.0
    CAO=    10.07   11.44      CC=  12.40    CC=  21.87
    NA2O=    2.36    2.68      KS=   0.0     HT=   0.0
    K2O=     1.76    2.00      NS=   0.0     WC=   0.0
    P2O5=    0.26    0.30      CS=   0.0     TN=   0.0
    H2O+=    0.20                            RU=   0.0
    H2O-=    0.36                            AC=   0.0
    CR2O3=   0.0     0.00
    NIO=     0.0     0.00
    CO2=     8.47
   TOTALS   97.10  100.01           54.93         45.07

      RATIOS       PL= -33.24     EN=  58.79     OL=   0.0


JUAD21       1     0
    SIO2=   49.64   51.01      QZ=   0.0     DI=   1.09
    TIO2=    3.53    3.63      OR=  11.76    HY=   0.0    (EN=  0.0     FS=  0.0 )
    AL2O3=  19.78   20.33      AB=  40.97    OL=   8.11   (FO=  7.04    FA=  1.08)
    FE2O3=   1.89    1.95      AN=  27.08    MT=   2.02
    FEO=     4.76    4.90      NE=   1.98    IL=   5.02
    MNO=     0.17    0.18                    AP=   1.43
    MGO=     3.33    3.43      LE=   0.0
    CAO=     6.77    6.96      CC=   0.0     CC=   0.0
    NA2O=    4.83    4.97      KS=   0.0     HT=   0.0
    K2O=     1.95    2.01      NS=   0.0     WC=   0.0
    P2O5=    0.67    0.69      CS=   0.0     TN=   0.0
    H2O+=    2.65                            RU=   0.0
    H2O-=    0.02                            AC=   0.0
    CR2O3=   0.0     0.00
    NIO=     0.0     0.00
    CO2=     0.0
   TOTALS   99.99  100.01           81.78         17.67

      RATIOS       PL=  39.80     EN=   0.0      OL=  86.74
```

```
JLSS22       1     0
    SIO2=   63.01   66.16     QZ=   2.67    DI=   0.0
    TIO2=    0.13    0.14     OR=   2.24    HY=   0.52    (EN=   0.16     FS=   0.36)
    AL2O3=  18.48   19.41     AB=  87.51    OL=   0.0     (FO=   0.0      FA=   0.0 )
    FE2O3=   0.06    0.07     AN=   0.10    MT=   0.06
    FEO=     0.32    0.34     NE=   0.0     IL=   0.18
    MNO=     0.06    0.07                   AP=   0.12
    MGO=     0.06    0.07     LE=   0.0
    CAO=     2.66    2.80     CO=   1.65✓   CC=   4.95
    NA2O=   10.01   10.52     KS=   0.0     HT=   0.0
    K2O=     0.39    0.41     NS=   0.0     WO=   0.0
    P2O5=    0.06    0.07     CS=   0.0     TN=   0.0
    H2O+=    0.27                           RU=   0.0
    H2O-=    0.05                           AC=   0.0
    CR2O3=   0.0     0.00
    NIO=     0.0     0.00
    CO2=     2.01
  TOTALS    97.57  100.01          94.17          5.83

      RATIOS      PL=   0.11     EN=  31.11     OL=   0.0
```

ST. LAWRENCE QUADRANGLE

```
SLNS80       1     0
    SIO2=   54.00   55.55     QZ=   0.0     DI=   3.74
    TIO2=    0.44    0.46     OR=  53.03    HY=   0.0     (EN=   0.0      FS=   0.0 )
    AL2O3=  21.30   21.92     AB=   3.13    OL=   0.0     (FO=   0.0      FA=   0.0 )
    FE2O3=   2.30    2.37     AN=  10.42    MT=   0.83
    FEO=     0.60    0.62     NE=  23.38✓   IL=   0.61
    MNO=     0.15    0.16                   AP=   0.15
    MGO=     0.25    0.26     LE=   0.0
    CAO=     4.40    4.53     CO=   0.0     CC=   1.31
    NA2O=    4.70    4.84     KS=   0.0     HT=   1.05
    K2O=     9.00    9.26     NS=   0.0     WO=   2.36
    P2O5=    0.07    0.08     CS=   0.0     TN=   0.0
    H2O+=    1.60                           RU=   0.0
    H2O-=    0.13                           AC=   0.0
    CR2O3=   0.0     0.00
    NIO=     0.0     0.00
    CO2=     0.52
  TOTALS    99.46  100.01          89.96         10.04

      RATIOS      PL=  76.90     EN=   0.0      OL=   0.0
```

```
LNS81      1    C
   SIO2=  54.40  55.62    QZ=  0.0     DI=  1.85
   TIO2=   0.23   0.24    OR= 52.54    HY=  0.0     (EN=  0.0     FS=  0.0 )
   AL2O3= 23.10  23.62    AB=  4.18    OL=  0.0     (FO=  0.0     FA=  0.0 )
   FE2O3=  1.20   1.23    AN=  6.38    MT=  1.23
   FEO=    0.76   0.78    NE= 32.24    IL=  0.31
   MNO=    0.11   0.12                 AP=  0.04
   MGO=    0.09   0.10    LE=  0.0
   CAO=    2.20   2.25    CO=  0.0     CC=  0.25
   NA2O=   6.60   6.75    KS=  0.0     HT=  0.0
   K2O=    9.10   9.31    NS=  0.0     WC=  0.98
   P2O5=   0.02   0.03    CS=  0.0     TN=  0.0
   H2O+=   1.20                        RU=  0.0
   H2O-=   0.16                        AC=  0.0
   CR2O3=  0.0    0.00
   NIO=    0.0    0.00
   CO2=    0.10
  TOTALS  99.27 100.01        95.34         4.66

    RATIOS     PL=  60.41    EN=   0.0     OL=   0.0
```

```
SLNS82      1    C
   SIO2=  54.00  55.67    QZ=  0.0     DI=  3.74
   TIO2=   0.44   0.46    OR= 53.11    HY=  0.0     (EN=  0.0     FS=  0.0 )
   AL2O3= 21.30  21.96    AB=  3.13    OL=  0.0     (FO=  0.0     FA=  0.0 )
   FE2O3=  2.10   2.17    AN= 10.43    MT=  0.83
   FEO=    0.60   0.62    NE= 23.41    IL=  0.61
   MNO=    0.15   0.16                 AP=  0.15
   MGO=    0.25   0.26    LE=  0.0
   CAO=    4.40   4.54    CO=  0.0     CC=  1.31
   NA2O=   4.70   4.85    KS=  0.0     HT=  0.91
   K2O=    9.00   9.28    NS=  0.0     WC=  2.36
   P2O5=   0.07   0.08    CS=  0.0     TN=  0.0
   H2O+=   1.60                        RU=  0.0
   H2O-=   0.13                        AC=  0.0
   CR2O3=  0.0    0.00
   NIO=    0.0    0.00
   CO2=    0.52
  TOTALS  99.26 100.01        90.08         9.92

    RATIOS     PL=  76.90    EN=   0.0     OL=   0.0
```

```
SLNS83       1     0
    SIO2=   54.40   55.62      QZ=  0.0      DI=   1.85
    TIO2=    0.23    0.24      OR= 52.54     HY=   0.0     (EN=   0.0     FS=  0.0 )
    AL2O3=  23.10   23.62      AB=   4.18    OL=   0.0     (FO=   0.0     FA=  0.0 )
    FE2O3=   1.20    1.23      AN=   6.38    MT=   1.23
    FEO=     0.76    0.78      NE= 32.24     IL=   0.31
    MNO=     0.11    0.12                    AP=   0.04
    MGO=     0.09    0.10      LE=  0.0
    CAO=     2.20    2.25      CO=  0.0      CC=   0.25
    NA2O=    6.60    6.75      KS=  0.0      HT=   0.0
    K2O=     9.10    9.31      NS=  0.0      WO=   0.98
    P2O5=    0.02    0.03      CS=  0.0      TN=   0.0
    H2O+=    1.20                            RU=   0.0
    H2O-=    0.16                            AC=   0.0
    CR2O3=   0.0     0.00
    NIO=     0.0     0.00
    CO2=     0.10
   TOTALS   99.27  100.01          95.34           4.66

      RATIOS      PL=  60.41     EN=    0.0      OL=    0.0
```

SELAWIK QUADRANGLE

```
SWBP45       1     0
    SIO2=   44.50   45.36      QZ=  0.0      DI= 49.00
    TIO2=    2.00    2.04      OR=  0.0      HY=  0.0      (EN=   0.0     FS=  0.0 )
    AL2O3=  11.00   11.22      AB=  0.0      OL= 42.81     (FO= 34.04     FA=  8.77)
    FE2O3=   4.30    4.39      AN= 12.46     MT=  4.63
    FEO=     7.70    7.85      NE=  6.11     IL=  2.87
    MNO=     0.21    0.22                    AP=  2.59
    MGO=     9.10    9.28      LE= 21.44
    CAO=    12.60   12.85      CO=  0.0      CC=  0.13
    NA2O=    1.10    1.13      KS=  0.0      HT=  0.0
    K2O=     4.40    4.49      NS=  0.0      WO=  0.0
    P2O5=    1.20    1.23      CS=-10.60     TN=  0.0
    H2O+=    1.50                            RU=  0.0
    H2O-=    0.29                            AC=  0.0
    CR2O3=   0.0     0.00
    NIO=     0.0     0.00
    CO2=     0.05
   TOTALS   99.95  100.01          29.41         102.04

      RATIOS      PL= 100.00     EN=    0.0      OL=  79.51
```

```
SWIJ46       1      0
    SIO2=   45.10   45.89     QZ=   0.0      DI= 57.95
    TIO2=    0.38    0.39     OR=   0.0      HY=  0.0     (EN=  0.0     FS=  0.0 )
    AL2O3= 15.00   15.27      AB=   0.0      OL= 21.73    (FO=  0.0     FA= 21.73)
    FE2O3=  5.10    5.19      AN=   0.0      MT=  4.95
    FEO=    5.10    5.19      NE= 36.60✓     IL=  0.52
    MNO=    0.43    0.44                     AP=  1.40
    MGO=    4.40    4.48      LE= 15.87✓
    CAO=   11.70   11.91      CC=   0.0      CC=  0.45
    NA2O=   7.00    7.13      KS=   0.0      HT=  0.0
    K2O=    3.40    3.46      NS=   0.0      WO=  0.0
    P2O5=   0.68    0.70      CS= -9.31      TN=  0.0
    H2O+=   1.00                             RU=  0.0
    H2O-=   0.27                             AC=  0.84✓
    CR2O3=  0.0     0.00
    NIO=    0.0     0.00
    CO2=    0.18
  TOTALS   99.74  100.01         43.15            87.84

      RATIOS      PL=   0.0      EN=   0.0      OL=   0.0


WMG47       1      0
    SIO2=   48.90   49.82     QZ=   0.0      DI= 16.23
    TIO2=    1.60    1.63     OR=   9.51     HY=  0.0     (EN=  0.0     FS=  0.0 )
    AL2O3= 12.10   12.33      AB=   0.0      OL= 21.63    (FO= 18.35    FA=  3.27)
    FE2O3=  2.60    2.65      AN= 11.12      MT=  2.77
    FEO=    5.20    5.30      NE=   4.99✓    IL=  2.27
    MNO=    0.17    0.18                     AP=  1.47
    MGO=    8.70    8.87      LE= 21.76✓
    CAO=   11.20   11.41      CG=   0.0      CC=  0.13
    NA2O=   0.91    0.93      KS=   0.0      HT=  0.0
    K2O=    6.10    6.22      NS=   0.0      WO=  0.0
    P2O5=   0.69    0.71      CS=   0.0      TN=  0.0
    H2O+=   1.40                             RU=  0.0
    H2O-=   0.49                             AC=  0.0
    CR2O3=  0.0     0.00
    NIO=    0.0     0.00
    CO2=    0.05
  TOTALS  100.11  100.01         47.39            44.49

      RATIOS      PL= 100.00     EN=   0.0      OL= 84.87
```

SWMG48 1 0

SIO2=	50.30	51.34	QZ=	0.0	DI=	11.66		
TIO2=	1.20	1.23	OR=	35.51	HY=	0.0	(EN= 0.0	FS= 0.0)
AL2O3=	15.00	15.31	AB=	0.0	OL=	13.23	(FO= 11.38	FA= 1.85)
FE2O3=	3.40	3.48	AN=	11.76	MT=	3.62		
FEO=	4.00	4.09	NE=	13.16	IL=	1.70		
MNO=	0.17	0.18			AP=	1.51		
MGO=	5.40	5.52	LE=	1.89				
CAO=	9.10	9.29	CO=	0.0	CC=	0.13		
NA2O=	2.40	2.45	KS=	0.0	HT=	0.0		
K2O=	6.30	6.43	NS=	0.0	WO=	0.0		
P2O5=	0.71	0.73	CS=	0.0	TN=	0.0		
H2O+=	1.60				RU=	0.0		
H2O-=	0.24				AC=	0.0		
CR2O3=	0.0	0.00						
NIO=	0.0	0.00						
CO2=	0.05							
TOTALS	99.37	100.01		62.32		31.85		

RATIOS PL= 100.00 EN= 0.0 OL= 86.03

SWMG49 1 0

SIO2=	50.70	51.43	QZ=	0.0	DI=	31.38		
TIO2=	1.20	1.22	OR=	0.0	HY=	0.0	(EN= 0.0	FS= 0.0)
AL2O3=	17.80	18.06	AB=	0.0	OL=	11.77	(FO= 0.0	FA= 11.77)
FE2O3=	5.90	5.99	AN=	6.36	MT=	0.62		
FEO=	1.20	1.22	NE=	11.03	IL=	1.71		
MNO=	0.14	0.15			AP=	0.17		
MGO=	0.17	0.18	LE=	54.65				
CAO=	8.10	8.22	CO=	0.0	CC=	0.13		
NA2O=	2.00	2.03	KS=	0.0	HT=	3.79		
K2O=	11.30	11.47	NS=	0.0	WO=	0.0		
P2O5=	0.08	0.09	CS=	6.62	TN=	0.0		
H2O+=	1.10				RU=	0.0		
H2O-=	0.19				AC=	0.0		
CR2O3=	0.0	0.00						
NIO=	0.0	0.00						
CO2=	0.05							
TOTALS	99.93	100.01		78.66		49.58		

RATIOS PL= 100.00 EN= 0.0 OL= 0.0

SWSH50 1 0

SIO2=	51.40	52.22	QZ=	0.0	DI=	14.54		
TIO2=	1.20	1.22	OR=	30.22	HY=	0.0	(EN= 0.0	FS= 0.0)
AL2O3=	12.20	12.40	AB=	9.83	OL=	13.56	(FO= 13.56	FA= 0.0)
FE2O3=	6.20	6.30	AN=	8.85	MT=	4.26		
FEO=	2.70	2.75	NE=	6.23✓	IL=	1.71		
MNO=	0.17	0.18			AP=	1.84		
MGO=	6.40	6.51	LE=	0.0				
CAO=	10.10	10.27	CC=	0.0	CC=	0.13		
NA2O=	2.20	2.24	KS=	0.0	HT=	1.58		
K2O=	5.00	5.08	NS=	0.0	WO=	0.0		
P2O5=	0.86	0.88	CS=	0.0	TN=	0.0		
H2O+=	1.10				RU=	0.0		
H2O-=	0.30				AC=	0.0		
CR2O3=	0.0	0.00						
NIO=	0.0	0.00						
CO2=	0.05							
TOTALS	99.38	100.01		55.12		37.61		

RATIOS PL= 47.37 EN= 0.0 OL= 100.00

WMG51 1 0

SIO2=	52.20	52.94	QZ=	0.0	DI=	10.16		
TIO2=	1.20	1.22	OR=	43.50	HY=	0.0	(EN= 0.0	FS= 0.0)
AL2O3=	15.20	15.42	AB=	1.21	OL=	11.97	(FO= 9.61	FA= 2.36)
FE2O3=	2.80	2.84	AN=	7.41	MT=	2.95		
FEO=	4.20	4.26	NE=	14.49✓	IL=	1.69		
MNO=	0.15	0.16			AP=	1.41		
MGO=	4.60	4.67	LE=	0.0				
CAO=	7.50	7.61	CC=	0.0	CC=	0.13		
NA2O=	2.80	2.84	KS=	0.0	HT=	0.0		
K2O=	7.30	7.41	NS=	0.0	WO=	0.0		
P2O5=	0.67	0.68	CS=	0.0	TN=	0.0		
H2O+=	1.20				RU=	0.0		
H2O-=	0.19				AC=	0.0		
CR2O3=	0.0	0.00						
NIO=	0.0	0.00						
CO2=	0.05							
TOTALS	100.06	100.01		66.62		28.30		

RATIOS PL= 85.93 EN= 0.0 OL= 80.29

```
SWRR52       1      0
    SIO2=    52.40   55.32     QZ=   0.0     DI=   0.85
    TIO2=     1.10    1.17     OR=  63.69    HY=   0.0     (EN=  0.0     FS=  0.0 )
    AL2O3=   19.90   21.01     AB=   3.17    CL=   1.39    (FO=  1.39    FA=  0.0 )
    FE2O3=    2.80    2.96     AN=  14.19    MT=   0.86
    FEO=      1.20    1.27     NE=  11.07✓   IL=   1.60
    MNO=      0.14    0.15                   AP=   0.33
    MGO=      0.64    0.68     LE=   0.0
    CAO=      3.80    4.02     CC=   0.0     CO=   0.95
    NA2O=     2.30    2.43     KS=   0.0     HT=   1.47
    K2O=     10.30   10.88     NS=   0.0     WO=   0.0
    P2O5=     0.15    0.16     CS=   0.0     TN=   0.0
    H2O+=     3.30                           RU=   0.0
    H2O-=     0.84                           AC=   0.0
    CR2O3=    0.0     0.00
    NIO=      0.0     0.00
    CO2=      0.36
  TOTALS     99.23  100.01           92.12         7.46

   RATIOS       PL=  81.74      EN=    0.0      OL= 100.00
```

```
SWTR53       1      0
    SIO2=    54.30   56.54     QZ=   0.0     DI=   3.89
    TIO2=     0.71    0.74     OR=  43.70    HY=   0.0     (EN=  0.0     FS=  0.0 )
    AL2O3=   17.20   17.91     AB=  21.15    CL=   7.64    (FO=  6.81    FA=  0.83)
    FE2O3=    2.70    2.82     AN=  10.23    MT=   2.90
    FEO=      2.40    2.50     NE=   6.68✓   IL=   1.02
    MNO=      0.15    0.16                   AP=   0.62
    MGO=      3.20    3.34     LE=   0.0
    CAO=      4.40    4.59     CC=   0.0     CO=   0.21
    NA2O=     3.50    3.65     KS=   0.0     HT=   0.0
    K2O=      7.20    7.50     NS=   0.0     WO=   0.0
    P2O5=     0.29    0.31     CS=   0.0     TN=   0.0
    H2O+=     3.10                           RU=   0.0
    H2O-=     0.68                           AC=   0.0
    CR2O3=    0.0     0.00
    NIO=      0.0     0.00
    CO2=      0.08
  TOTALS     99.91  100.01           81.77        16.28

   RATIOS       PL=  32.60      EN=    0.0      OL=  89.09
```

SWJV54 1 C

SIO2=	55.40	56.60	QZ=	0.0	DI=	0.0		
TIO2=	0.28	0.29	OR=	42.08	HY=	0.0	(EN= 0.0	FS= 0.0)
AL2O3=	21.60	22.07	AB=	0.0	OL=	0.86	(FO= 0.27	FA= 0.59)
FE2O3=	0.60	0.62	AN=	2.71	MT=	0.63		
FEO=	1.00	1.03	NE=	7.03✓	IL=	0.39		
MNO=	0.03	0.04			AP=	0.13		
MGO=	0.13	0.14	LE=	45.09✓				
CAO=	0.89	0.91	CO=	0.55✓	CC=	0.53		
NA2O=	1.30	1.33	KS=	0.0	HT=	0.0		
K2O=	16.60	16.96	NS=	0.0	WC=	0.0		
P2O5=	0.06	0.07	CS=	0.0	TN=	0.0		
H2O+=	0.80				RU=	0.0		
H2O-=	0.12				AC=	0.0		
CR2O3=	0.0	0.00						
NIO=	0.0	0.00						
CO2=	0.21							
TOTALS	99.02	100.01		97.46		2.54		

RATIOS PL= 100.00 EN= 0.0 OL= 31.30

SWFY55 1 C

SIO2=	55.80	56.53	QZ=	0.0	DI=	9.67		
TIO2=	0.96	0.98	OR=	41.74	HY=	0.0	(EN= 0.0	FS= 0.0)
AL2O3=	15.20	15.40	AB=	15.04	OL=	9.12	(FO= 6.69	FA= 2.43)
FE2O3=	2.30	2.33	AN=	6.50	MT=	2.43		
FEO=	3.80	3.85	NE=	8.38✓	IL=	1.35		
MNO=	0.17	0.18			AP=	0.82		
MGO=	3.20	3.25	LE=	0.0				
CAO=	6.70	6.79	CO=	0.0	CC=	0.13		
NA2O=	3.20	3.25	KS=	0.0	HT=	0.0		
K2O=	7.00	7.10	NS=	0.0	WC=	0.0		
P2O5=	0.39	0.40	CS=	0.0	TN=	0.0		
H2O+=	1.00				RU=	0.0		
H2O-=	0.26				AC=	0.0		
CR2O3=	0.0	0.00						
NIO=	0.0	0.00						
CO2=	0.05							
TOTALS	100.03	100.01		71.65		23.51		

RATICS PL= 30.18 EN= 0.0 OL= 73.33

```
SWPK56[illegible]     1      0
     SIO2=   57.20    57.69      QZ=   0.0     DI=    2.75
     TIO2=    0.29     0.30      OR=  46.18    HY=    0.0     (EN=   0.0     FS=   0.0 )
     AL2O3=  21.40    21.59      AB=  16.98    CL=    0.0     (FO=   0.0     FA=   0.0 )
     FE2O3=   1.90     1.92      AN=   0.34    MT=    1.86
     FEO=     1.00     1.01      NE=  29.33✓   IL=    0.39
     MNO=     0.09     0.10                    AP=    0.06
     MGO=     0.15     0.16      LE=   0.0
     CAO=     1.40     1.42      CC=   0.0     CC=    0.12
     NA2O=    7.60     7.67      KS=   0.0     HT=    0.04
     K2O=     8.10     8.17      NS=   0.0     WC=    1.95
     P2O5=    0.03     0.04      CS=   0.0     TN=    0.0
     H2O+=    0.66                             RU=    0.0
     H2O-=    0.30                             AC=    0.0
     CR2O3=   0.0      0.00
     NIO=     0.0      0.00
     CO2=     0.05
    TOTALS  100.67   100.01           92.84           7.16

       RATIOS        PL=    1.98     EN=    0.0      OL=    0.0




SWJV57       1      C
     SIO2=   57.80    59.62      QZ=   0.0     DI=    0.0
     TIO2=    0.27     0.28      OR=  55.56    HY=    0.0     (EN=   0.0     FS=   0.0 )
     AL2O3=  22.10    22.80      AB=  23.94    OL=    0.91    (FO=   0.73    FA=   0.18)
     FE2O3=   0.54     0.56      AN=   4.75    MT=    0.56
     FEO=     0.60     0.62      NE=  10.97✓   IL=    0.38
     MNO=     0.04     0.05                    AP=    0.13
     MGO=     0.35     0.37      LE=   0.0
     CAO=     1.10     1.14      CC=   2.68✓   CC=    0.13
     NA2O=    4.70     4.85      KS=   0.0     HT=    0.0
     K2O=     9.40     9.70      NS=   0.0     WC=    0.0
     P2O5=    0.06     0.07      CS=   0.0     TN=    0.0
     H2O+=    2.40                             RU=    0.0
     H2O-=    0.39                             AC=    0.0
     CR2O3=   0.0      0.00
     NIO=     0.0      0.00
     CO2=     0.05
    TOTALS   99.80   100.01           97.90           2.10

       RATIOS        PL=   16.56     EN=    0.0      OL=   80.12
```

```
WFY58       1     C
   SIO2=   54.80   55.56     QZ=   0.0      DI=  19.86
   TIO2=    1.40    1.42     CR=  34.58     HY=   0.0     (EN=  0.0     FS=  0.0 )
   AL2O3=  15.60   15.82     AB=  17.77     OL=   0.0     (FO=  0.0     FA=  0.0 )
   FE2O3=   2.80    2.84     AN=   7.55     MT=   2.95
   FEO=     3.20    3.25     NE=  11.09     IL=   1.97
   MNO=     0.20    0.21                    AP=   0.93
   MGO=     2.50    2.54     LE=   0.0
   CAO=     7.90    8.01     CC=   0.0      CC=   0.13
   NA2O=    4.00    4.06     KS=   0.0      HT=   0.0
   K2O=     5.80    5.88     NS=   0.0      WO=   3.17
   P2O5=    0.44    0.45     CS=   0.0      TN=   0.0
   H2O+=    0.75                            RU=   0.0
   H2O-=    0.04                            AC=   0.0
   CR2O3=   0.0     0.00
   NIO=     0.0     0.00
   CO2=     0.05
  TOTALS   99.48  100.01          70.99           29.01

     RATIOS      PL=   29.83      EN=    0.0       OL=    0.0
```

```
SWPK59      1     C
   SIO2=   58.10   59.30     QZ=   0.0      DI=   0.0
   TIO2=    0.22    0.23     CR=  33.45     HY=   0.0     (EN=  0.0     FS=  0.0 )
   AL2O3=  22.00   22.46     AB=  40.07     OL=   0.64    (FO=  0.34    FA=  0.30)
   FE2O3=   1.40    1.43     AN=   5.92     MT=   1.43
   FEO=     1.00    1.03     NE=  17.50     IL=   0.30
   MNO=     0.09    0.10                    AP=   0.02
   MGO=     0.17    0.18     LE=   0.0
   CAO=     1.30    1.33     CC=   0.54     CC=   0.12
   NA2O=    7.90    8.07     KS=   0.0      HT=   0.0
   K2O=     5.30    5.92     NS=   0.0      WO=   0.0
   P2O5=    0.01    0.02     CS=   0.0      TN=   0.0
   H2O+=    1.20                            RU=   0.0
   H2O-=    0.11                            AC=   0.0
   CR2O3=   0.0     0.00
   NIO=     0.0     0.00
   CO2=     0.05
  TOTALS   99.35  100.01          97.49            2.51

     RATIOS      PL=   12.88      EN=    0.0       OL=   53.49
```

SWMZ62 1 0

SIO2=	61.70	63.16	QZ=	10.81	DI=	0.0		
TIO2=	0.78	0.80	OR=	32.17	HY=	8.30	(EN= 6.68	FS= 1.62)
AL2O3=	15.60	15.97	AB=	33.51	OL=	0.0	(FO= 0.0	FA= 0.0)
FE2O3=	1.90	1.95	AN=	8.16	MT=	2.00		
FEO=	2.50	2.56	NE=	0.0	IL=	1.10		
MNO=	0.09	0.10			AP=	0.67		
MGO=	2.40	2.46	LE=	0.0				
CAO=	3.30	3.38	CO=	0.78	CC=	2.50		
NA2O=	3.70	3.79	KS=	0.0	HT=	0.0		
K2O=	5.40	5.53	NS=	0.0	WO=	0.0		
P2O5=	0.32	0.33	CS=	0.0	TN=	0.0		
H2O+=	0.91				RU=	0.0		
H2O-=	0.19				AC=	0.0		
CR2O3=	0.0	0.00						
NIO=	0.0	0.00						
CO2=	0.98							
TOTALS	99.77	100.01		85.43		14.57		

RATIOS PL= 19.58 EN= 80.52 OL= 0.0

SWTS69 1 0

SIO2=	59.40	59.97	QZ=	0.0	DI=	5.76		
TIO2=	0.63	0.64	OR=	44.46	HY=	0.0	(EN= 0.0	FS= 0.0)
AL2O3=	16.60	16.76	AB=	29.55	OL=	4.99	(FO= 3.74	FA= 1.25)
FE2O3=	1.90	1.92	AN=	7.46	MT=	1.99		
FEO=	2.40	2.43	NE=	1.19	IL=	0.88		
MNO=	0.09	0.10			AP=	0.71		
MGO=	1.80	1.82	LE=	0.0				
CAO=	4.90	4.95	CO=	0.0	CC=	0.13		
NA2O=	3.50	3.54	KS=	0.0	HT=	0.0		
K2O=	7.50	7.58	NS=	0.0	WO=	0.0		
P2O5=	0.34	0.35	CS=	0.0	TN=	0.0		
H2O+=	0.42				RU=	0.0		
H2O-=	0.08				AC=	0.0		
CR2O3=	0.0	0.00						
NIO=	0.0	0.00						
CO2=	0.05							
TOTALS	99.61	100.01		82.66		14.46		

RATIOS PL= 20.16 EN= 0.0 OL= 74.99

WTS70	1	0					
SIO2=	55.40	56.50	QZ=	0.0	DI=	5.01	
TIO2=	0.97	0.99	OR=	40.34	HY=	0.0	(EN= 0.0 FS= 0.0)
AL2O3=	16.00	16.32	AB=	25.90	OL=	8.98	(FO= 6.75 FA= 2.23)
FE2O3=	2.90	2.96	AN=	10.61	MT=	2.98	
FEO=	3.90	3.98	NE=	0.93✓	IL=	1.38	
MNO=	0.11	0.12			AP=	1.24	
MGO=	3.20	3.27	LE=	0.0			
CAO=	5.40	5.51	CO=	0.0	CC=	0.13	
NA2O=	3.00	3.06	KS=	0.0	HT=	0.0	
K2O=	6.70	6.84	NS=	0.0	WO=	0.0	
P2O5=	0.58	0.60	CS=	0.0	TN=	0.0	
H2O+=	0.88				RU=	0.0	
H2O-=	0.11				AC=	0.0	
CR2O3=	0.0	0.00					
NIO=	0.0	0.00					
CO2=	0.05						
TOTALS	99.10	100.01		77.78		19.71	

RATIOS PL= 29.05 EN= 0.0 OL= 75.22

WMZ72	1	0					
SIO2=	71.40	72.54	QZ=	28.91	DI=	0.0	
TIO2=	0.18	0.19	OR=	21.95	HY=	1.27	(EN= 0.97 FS= 0.30)
AL2O3=	15.50	15.75	AB=	37.87	OL=	0.0	(FO= 0.0 FA= 0.0)
FE2O3=	0.64	0.66	AN=	2.42	MT=	0.67	
FEO=	0.60	0.61	NE=	0.0	IL=	0.25	
MNO=	0.04	0.05			AP=	0.06	
MGO=	0.35	0.36	LE=	0.0			
CAO=	1.80	1.83	CO=	4.06✓	CC=	2.54	
NA2O=	4.20	4.27	KS=	0.0	HT=	0.0	
K2O=	3.70	3.76	NS=	0.0	WO=	0.0	
P2O5=	0.03	0.04	CS=	0.0	TN=	0.0	
H2O+=	0.53				RU=	0.0	
H2O-=	0.09				AC=	0.0	
CR2O3=	0.0	0.00					
NIO=	0.0	0.00					
CO2=	1.00						
TOTALS	100.06	100.01		95.21		4.79	

RATIOS PL= 6.01 EN= 76.59 OL= 0.0

SWTF74 1 0

SIO2=	54.80	55.56	QZ= 0.0	DI= 19.36			
TIO2=	1.40	1.42	OR= 34.58	HY= 0.0	(EN= 0.0	FS= 0.0)	
AL2O3=	15.60	15.82	AB= 17.77	OL= 0.0	(FO= 0.0	FA= 0.0)	
FE2O3=	2.80	2.84	AN= 7.55	MT= 2.95			
FEO=	3.20	3.25	NE= 11.09✓	IL= 1.97			
MNO=	0.20	0.21		AP= 0.93			
MGO=	2.50	2.54	LE= 0.0				
CAO=	7.90	8.01	CO= 0.0	CC= 0.13			
NA2O=	4.00	4.06	KS= 0.0	HT= 0.0			
K2O=	5.80	5.88	NS= 0.0	WO= 3.17			
P2O5=	0.44	0.45	CS= 0.0	TN= 0.0			
H2O+=	0.75			RU= 0.0			
H2O-=	0.04			AC= 0.0			
CR2O3=	0.0	0.00					
NIO=	0.0	0.00					
CO2=	0.05						
TOTALS	99.48	100.01	70.99	29.01			

RATIOS PL= 29.83 EN= 0.0 OL= 0.0

SWPK79 1 0

SIO2=	58.40	59.39	QZ= 0.0	DI= 2.44			
TIO2=	0.76	0.78	OR= 58.55	HY= 0.0	(EN= 0.0	FS= 0.0)	
AL2O3=	18.20	18.51	AB= 19.81	OL= 2.46	(FO= 1.88	FA= 0.58)	
FE2O3=	2.10	2.14	AN= 6.88	MT= 2.22			
FEO=	2.00	2.04	NE= 5.00✓	IL= 1.07			
MNO=	0.12	0.13		AP= 0.34			
MGO=	0.90	0.92	LE= 0.0				
CAO=	2.80	2.85	CO= 0.0	CC= 0.0			
NA2O=	3.10	3.16	KS= 0.0	HT= 0.0			
K2O=	9.80	9.97	NS= 0.0	WO= 0.0			
P2O5=	0.16	0.17	CS= 0.0	TN= 0.0			
H2O+=	1.00			RU= 0.0			
H2O-=	0.09			AC= 0.0			
CR2O3=	0.0	0.00					
NIO=	0.0	0.00					
CO2=	0.0						
TOTALS	99.43	100.01	90.24	8.54			

RATIOS PL= 25.78 EN= 0.0 OL= 76.48

```
WLM79      1     C
   SIO2=  49.60  50.60    QZ=  0.0     DI= 17.99
   TIO2=   0.91   0.93    OR=  2.61    HY=  0.0    (EN=  0.0    FS=  0.0 )
   AL2O3= 11.60  11.84    AB=  0.0     OL= 26.13   (FO= 21.40   FA=  4.73)
   FE2O3=  1.50   1.53    AN=  7.79    MT=  1.57
   FEO=    5.40   5.51    NE= 10.27    IL=  1.27
   MNO=    0.15   0.16                 AP=  0.80
   MGO=   10.30  10.51    LE= 22.57
   CAO=   11.10  11.33    CO=  0.0     CC=  0.0
   NA2O=   1.90   1.94    KS=  0.0     HT=  0.0
   K2O=    5.20   5.31    NS=  0.0     WC=  0.0
   P2O5=   0.38   0.39    CS=  0.0     TN=  0.0
   H2O+=   1.40                        RU=  0.0
   H2O-=   0.18                        AC=  0.0
   CR2O3=  0.0    0.00
   NIO=    0.0    0.00
   CO2=    0.0
  TOTALS  99.62 100.01        43.24       47.76

     RATIOS     PL= 100.00    EN=   0.0     OL=  81.90
```

TANACROSS QUADRANGLE

```
CSY89      1     C
   SIO2=  55.38  55.67    QZ=  0.0     DI=  4.48
   TIO2=   0.55   0.56    OR= 31.80    HY=  0.0    (EN=  0.0    FS=  0.0 )
   AL2O3= 18.98  19.08    AB= 27.96    OL=  6.26   (FO=  3.28   FA=  2.98)
   FE2O3=  2.65   2.67    AN= 15.14    MT=  2.76
   FEO=    4.16   4.19    NE=  7.92    IL=  0.76
   MNO=    0.10   0.11                 AP=  0.67
   MGO=    1.59   1.60    LE=  0.0
   CAO=    5.75   5.79    CC=  0.0     CC=  0.0
   NA2O=   4.60   4.63    KS=  0.0     HT=  0.0
   K2O=    5.40   5.43    NS=  0.0     WC=  0.0
   P2O5=   0.32   0.33    CS=  0.0     TN=  0.0
   H2O+=   0.58                        RU=  0.0
   H2O-=   0.01                        AC=  0.0
   CR2O3=  0.0    0.00
   NIO=    0.0    0.00
   CO2=    0.0
  TOTALS 100.07 100.01        82.82       14.94

     RATIOS     PL=  35.13    EN=   0.0     OL=  52.40
```

TANANA QUADRANGLE

```
TNMZ02       1      0
   SIO2=   51.74   52.35     QZ=   0.0     DI=   1.65
   TIO2=    1.03    1.05     OR=  37.30    HY=   0.0     (EN=  0.0     FS=  0.0 )
   AL2O3=  19.11   19.34     AB=  14.87    OL=  14.84    (FO=  7.21    FA=  7.63)
   FE2O3=   1.05    1.07     AN=  23.94    MT=   1.11
   FEO=     7.74    7.84     NE=   3.49    IL=   1.46
   MNO=     0.13    0.14                   AP=   0.51
   MGO=     3.43    3.47     LE=   0.0
   CAO=     5.89    5.96     CO=   0.0     CC=   0.0
   NA2O=    2.27    2.30     KS=   0.0     HT=   0.0
   K2O=     6.22    6.30     NS=   0.0     WO=   0.0
   P2O5=    0.24    0.25     CS=   0.0     TN=   0.0
   H2O+=    1.06                           RU=   0.0
   H2O-=    0.08                           AC=   0.0
   CR2O3=   0.0     0.00
   NIO=     0.0     0.00
   CO2=     0.0
  TOTALS   99.99  100.01          79.60         19.57

     RATIOS      PL=   61.68     EN=    0.0      OL=   48.57
```

TAYLOR MOUNTAINS QUADRANGLE

```
TABG06       1      0
   SIO2=   70.49   71.54     QZ=  28.61    DI=   0.0
   TIO2=    0.45    0.46     OR=  33.23    HY=   5.04    (EN=  0.82    FS=  4.22)
   AL2O3=  13.97   14.18     AB=  25.53    OL=   0.0     (FO=  0.0     FA=  0.0 )
   FE2O3=   0.43    0.44     AN=   1.55    MT=   0.46
   FEO=     3.21    3.26     NE=   0.0     IL=   0.64
   MNO=     0.04    0.05                   AP=   0.47
   MGO=     0.29    0.30     LE=   0.0
   CAO=     1.18    1.20     CO=   3.28    CC=   1.19
   NA2O=    2.77    2.82     KS=   0.0     HT=   0.0
   K2O=     5.48    5.57     NS=   0.0     WO=   0.0
   P2O5=    0.22    0.23     CS=   0.0     TN=   0.0
   H2O+=    0.62                           RU=   0.0
   H2O-=    0.18                           AC=   0.0
   CR2O3=   0.0     0.00
   NIO=     0.0     0.00
   CO2=     0.46
  TOTALS   99.78  100.01          92.19          7.81

     RATIOS      PL=    5.72     EN=   16.31     OL=    0.0
```

```
LGR84      1     0
   SIO2=  73.93   74.38     QZ= 30.81    DI=  0.0
   TIO2=   0.12    0.13     OR= 21.12    HY=  3.09    (EN=  1.34    FS=  1.75)
   AL2O3= 14.70   14.79     AB= 38.72    CL=  0.0     (FO=  0.0     FA=  0.0 )
   FE2O3=  0.41    0.42     AN=  2.24    MT=  0.43
   FEO=    1.40    1.41     NE=  0.0     IL=  0.17
   MNO=    0.01    0.02                  AP=  0.08
   MGO=    0.48    0.49     LE=  0.0
   CAO=    0.50    0.51     CO=  3.34✓   CC=  0.0
   NA2O=   4.27    4.30     KS=  0.0     HT=  0.0
   K2O=    3.54    3.57     NS=  0.0     WO=  0.0
   P2O5=   0.04    0.05     CS=  0.0     TN=  0.0
   H2O+=   0.34                          RU=  0.0
   H2O-=   0.0                           AC=  0.0
   CR2O3=  0.0     0.00
   NIO=    0.0     0.00
   CO2=    0.0
  TOTALS  99.74  100.01         96.23         3.77

     RATIOS      PL=    5.47     EN=  43.36     OL=    0.0
```

```
TLGR85      1     0
    SIO2=  74.80   76.64     QZ= 31.34    DI=  0.0
    TIO2=   0.02    0.03     OR= 26.14    HY=  1.54    (EN=  0.28    FS=  1.26)
    AL2O3= 12.90   13.22     AB= 37.88    CL=  0.0     (FO=  0.0     FA=  0.0 )
    FE2O3=  0.10    0.11     AN=  1.92    MT=  0.11
    FEO=    0.82    0.85     NE=  0.0     IL=  0.03
    MNO=    0.03    0.04                  AP=  0.0
    MGO=    0.10    0.11     LE=  0.0
    CAO=    0.44    0.46     CO=  0.92✓   CC=  0.13
    NA2O=   4.10    4.21     KS=  0.0     HT=  0.0
    K2O=    4.30    4.41     NS=  0.0     WO=  0.0
    P2O5=   0.0     0.00     CS=  0.0     TN=  0.0
    H2O+=   0.27                          RU=  0.0
    H2O-=   0.26                          AC=  0.0
    CR2O3=  0.0     0.00
    NIO=    0.0     0.00
    CO2=    0.05
   TOTALS  98.19  100.01         98.19         1.81

      RATIOS      PL=    4.83     EN=  18.46     OL=    0.0
```

```
TLGR86      1     0
    SIO2=   76.50   77.11      QZ= 32.47    DI=   0.0
    TIO2=    0.02    0.03      OR= 25.75    HY=   1.52   (EN=   0.28    FS=   1.24)
    AL2O3=  12.80   12.91      AB= 37.32    CL=   0.0    (FO=   0.0     FA=   0.0 )
    FE2O3=   0.10    0.11      AN=  1.89    MT=   0.11
    FEO=     0.82    0.83      NE=  0.0     IL=   0.03
    MNO=     0.03    0.04                   AP=   0.0
    MGO=     0.10    0.11      LE=  0.0
    CAO=     0.44    0.45      CO=  0.79✓   CC=   0.13
    NA2O=    4.10    4.14      KS=  0.0     HT=   0.0
    K2O=     4.30    4.34      NS=  0.0     WO=   0.0
    P2O5=    0.0     0.00      CS=  0.0     TN=   0.0
    H2O+=    0.27                           RU=   0.0
    H2O-=    0.26                           AC=   0.0
    CR2O3=   0.0     0.00
    NIO=     0.0     0.00
    CO2=     0.05
   TOTALS   99.79  100.01          98.22          1.78

     RATIOS      PL=    4.83     EN=  18.46     OL=    0.0
```

```
TLGR87      1     0
    SIO2=   71.30   71.82      QZ= 21.52    DI=   0.0
    TIO2=    0.21    0.22      OR= 31.52    HY=   3.80   (EN=   2.22    FS=   1.57)
    AL2O3=  14.40   14.51      AB= 37.05    CL=   0.0    (FO=   0.0     FA=   0.0 )
    FE2O3=   0.56    0.57      AN=  4.78    MT=   0.59
    FEO=     1.40    1.42      NE=  0.0     IL=   0.29
    MNO=     0.05    0.06                   AP=   0.13
    MGO=     0.80    0.81      LE=  0.0
    CAO=     1.10    1.11      CO=  0.20✓   CC=   0.13
    NA2O=    4.10    4.13      KS=  0.0     HT=   0.0
    K2O=     5.30    5.34      NS=  0.0     WO=   0.0
    P2O5=    0.06    0.07      CS=  0.0     TN=   0.0
    H2O+=    0.56                           RU=   0.0
    H2O-=    0.18                           AC=   0.0
    CR2O3=   0.0     0.00
    NIO=     0.0     0.00
    CO2=     0.05
   TOTALS  100.07  100.01          95.06          4.94

     RATIOS      PL=   11.43     EN=  58.54     OL=    0.0
```

TIGRER 1 0

SIO2=	73.80	74.51	QZ=	29.96	DI=	0.0		
TIO2=	0.18	0.19	OR=	28.85	HY=	3.14	(EN= 1.54	FS= 1.60)
AL2O3=	13.60	13.74	AB=	31.97	CL=	0.0	(FO= 0.0	FA= 0.0)
FE2O3=	0.37	0.33	AN=	3.80	MT=	0.39		
FEO=	1.30	1.32	NE=	0.0	IL=	0.26		
MNO=	0.04	0.05			AP=	0.09		
MGO=	0.55	0.56	LE=	0.0				
CAO=	0.37	0.08	CC=	1.42✓	CC=	0.13		
NA2O=	3.50	3.54	KS=	0.0	HT=	0.0		
K2O=	4.80	4.85	NS=	0.0	WO=	0.0		
P2O5=	0.04	0.05	CS=	0.0	TN=	0.0		
H2O+=	0.73				RU=	0.0		
H2O-=	0.0				AC=	0.0		
CR2O3=	0.0	0.00						
NIO=	0.0	0.00						
CO2=	0.05							
TOTALS	99.83	100.01		96.00		4.00		

RATIOS PL= 10.63 EN= 49.20 OL= 0.0

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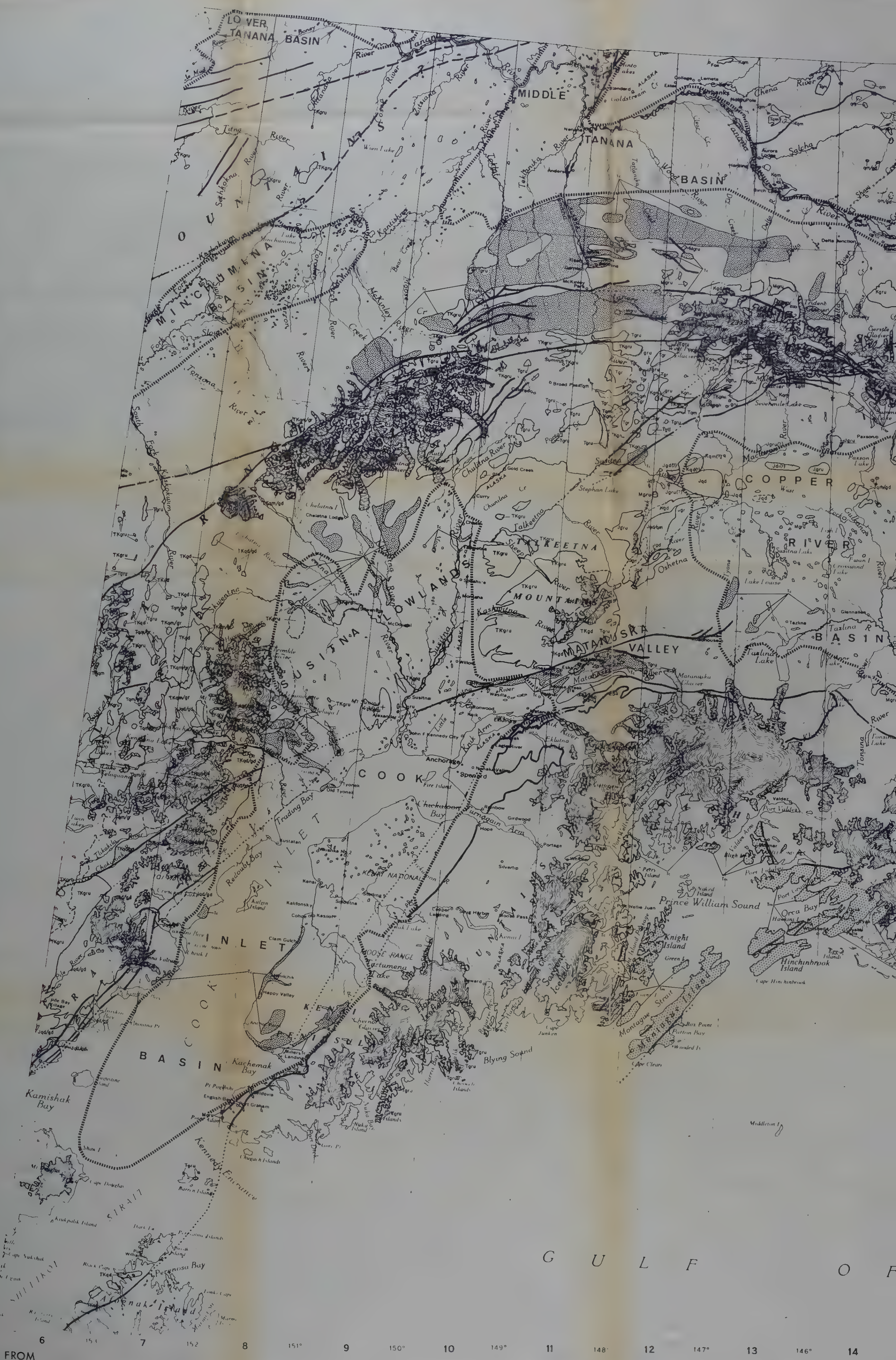

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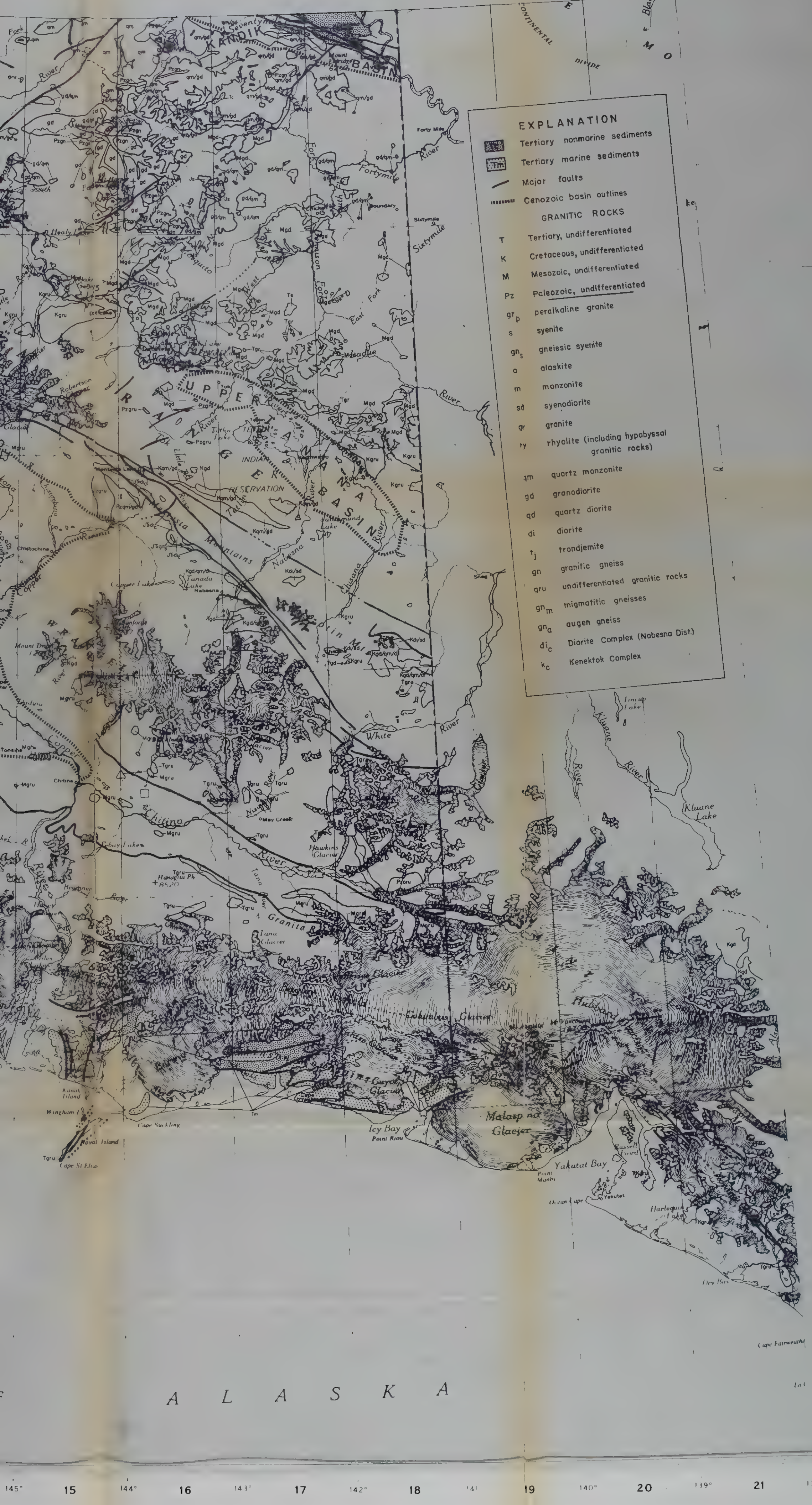

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